JOURNAL
OF THE
FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA,
FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXLII. OCTOBER, 1896. No. 4

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HEAT-WASTES IN STEAM-ENGINE CYLINDERS.*
(ABSTRACT.)

BY ROBERT H. THURSTON.

INTRODUCTION.

The paper, of which the following is an abstract, was read before the British Institution of Naval Architects, at its thirty-sixth session, 1895, and is printed *in extenso* in the *Transactions* of that association, presently to be published. It is intended to give a condensed statement of the condition of the theory of the heat wastes in the steam-engine cylinder, and especially of the method of so-called cylinder condensation, which constitutes the most important of the controllable wastes of the heat-engines. As a statement of the state of the art and of the theory to date, this paper necessarily contains no important original matter, and all its essential facts have been at one or another time pub-

* *Transactions*, Institution Naval Architects, 1895.

lished, and in large proportion in the *Journal of the Franklin Institute* and in the *Transactions* of the American Society of Mechanical Engineers; but this has been thought an appropriate time for their collection and formal arrangement, with a view to exhibiting the status which has been reached at the present time.

Before taking up the paper in question, it may be well to review briefly the earlier history of the study of heat-wastes in the heat-engines. This had been done by the author of the paper, in a contribution to the *Transactions* of the British Association for Advancement of Science, at the Montreal Meeting of 1884, and the outline then given will serve, perhaps, as a satisfactory introduction to the later discussion.*

"A complete history of the development of the theory of the steam-engine would include: (1) the history of the mechanical theory of heat; (2) the history of the science of thermodynamics, which has been the outgrowth of that theory; (3) the history of the application of the science of heat-transformation to the case of the steam-engine; and (4) an account of the completion of the theory of the steam- and other heat-engines by the introduction of the theory of losses by the more or less avoidable forms of waste, as distinguished from those necessary and unavoidable wastes indicated by the pure theory of thermodynamics. The first and second of these divisions are treated of in works on thermodynamics, and in treatises on physics. The third division is briefly considered, and usually very incompletely, in treatises on the steam-engine; while the last is of too recent development to be the subject of complete treatment, as yet, in any existing works.

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"Of all the heat sent forward by the steam boiler to the engine, a certain part, definite in amount and easily calculated when the power developed is known, is expended by

* *Transactions* British Association for Advancement of Science, Montreal Meeting, 1884; *Journal Franklin Institute*, October, 1884; Manual of the Steam-Engine, Chap. III.

transformation into mechanical energy; another part, equally definite and easily calculated, also, is expended as the necessarily occurring waste which must take place in all such transformations at usual temperatures of reception and rejection of heat; still another portion is lost by conduction and radiation to surrounding bodies; and finally, a part, often very large in comparison with even the first and principal of these quantities, is wasted by transfer, within the engine, from the induction to the eduction side, 'from steam to exhaust,' by a singular and interesting process, without conversion into useful effect. The science of thermodynamics only takes cognizance of the first, which is sometimes one of the smallest of these expenditures. The science of the general physics of heat takes cognizance of the others.

* * * * * * *

"Chronologically considered, the history of the growth of the theory of the steam-engine divides itself distinctly into three periods: the first extending up to the middle of the present century, and mainly distinguished by the attempts of Carnot and of Clapeyron to formulate a physical theory of the thermodynamics of the machine; the second beginning with the date of the work of Rankine and Clausius, who constructed a correct thermodynamic theory; and the third beginning a generation later, and marked by the introduction, into the general theory, of the physics of the conduction and transfer of that heat which plays no part in the useful transformation of energy. The first period may be said to include, also, the inauguration of experimental investigation, and the discovery of the nature and extent of avoidable wastes, and attempts at their amelioration, by James Watt and by John Smeaton. The second period is marked by the attempt on the part of a number of engineers to determine the method and magnitude of these wastes by more thorough and systematic investigation, and the exact enunciation of the law governing the necessary rejection of heat, as revealed by the science of thermodynamics. The third period is opening with promise of a

complete and practically applicable investigation of all the methods of loss of energy in the engine, and of the determination, by both theoretical and experimental research, of all the data needed for the construction of a working theory.

"M. Hirn has recognized these three periods, and has proposed to call the second the 'theoretical' and the third the 'experimental' stage. The writer would prefer to make the nomenclature somewhat more accordant with what has seemed to him to be the true method of development of the subject. It has been seen that the experimental stage really began with the investigations of Watt in the first period, and that the work of experimentation was continued through the second into the present, the last period.

"It is also evident that the theoretical stage, if it can be properly said that such a period may be marked off in the history of the theory of the steam-engine, actually extends into the present epoch, since the work of the engineer and the physicist of to-day consists in the application of the science of heat-transfer and heat-transformation, together, to the engine. During the second period, the theory included only the thermodynamics of the engine; while the third period is about to incorporate the theory of conduction and radiation into the general theory, with the already established theory of heat-transformation. The writer would, therefore, make the classification of these successive stages in the progress here described, thus:

"(1) Primary Period.—That of incomplete investigation and of earliest systematic, but inaccurate, theory.

"(2) Secondary Period.—That of the establishment of a correct thermodynamic theory, the *Theory of the Ideal Engine*.

"(3) Tertiary Period.—That of the production of the complete theory of the engine, of the *true Theory of the Real Engine*.

The work of developing this theory is still incomplete. It remains to be determined by experiment precisely what are the laws of transfer of heat between metal and vapor, in the engine cylinder, and to apply these laws in the theory of the machine."

In the present paper are exhibited the later developments of the study of the heat-wastes of the engine, the scientific discussion of which is expected ultimately to supply the still missing link in the theory of the real engine as distinguished from the ideal thermodynamic machine, and which may thus, perhaps, ere long, permit the construction of a complete and rational theory of the heat-engines, including the physical as well as the thermodynamical elements of that complete theory.

HEAT-WASTES OF THE STEAM ENGINE.

The following preliminary study of the facts of the case, as illustrated by the action of several different classes of engine, may prove interesting, and possibly useful, as leading the way to the more exact quantitative investigation that must ensue to give us the desired mathematical expression of the quantity and rate of heat exchange. The method pursued is the familiar one of laying down a "saturation curve"—exhibiting the variations of pressure and volume of the given weight of steam, constituting a working charge, when retained in the "dry and saturated state" throughout the range of volumetric change illustrated in the engine cylinder, and as shown on the indicator diagram—and placing beside it the expansion line of the diagram itself. The relative magnitudes of the volumes indicated on the curves of the diagram, and on the standard thus laid down, being taken at a common pressure in each case, measure the proportions of steam existing in the mixture in the engine cylinder at the instants taken. The variations of this proportion measure in turn the variations of composition of the working charge. The "quality" of the fluid is thus at every instant determinable, and is customarily measured as a fraction, completely dry steam being taken as unity. The several figures given herewith illustrate this method clearly. The value of the saturation curve as a base line, or reference curve, was, perhaps, first revealed by Professor Cotterill. It has been used extensively in Sibley College work, in connection with such investigations as those here in part described, and the Col-

lege has made it a standard system of measurement of heat and steam variations, for a considerable time, in the work of the Department of Experimental Engineering.* The use of the adiabatic expansion curve, in a similar manner, permits the comparison of the work performed in the actual case with that which would be done by the same weight of steam supplied to a non-conducting cylinder, as well as the amount of initial condensation.† It does not, however, permit the determination of the quality of the steam and its variations throughout the stroke, which is what is here required. In many cases a simple equilateral hyperbola will give a reference line of sufficient exactness of location for the purposes of the engineer, as the indices of the three curves only vary as the numbers 1·000, 1·0646, 1·135, and for moderate ratios of expansion the lines are very nearly coincident. For present purposes the saturation line, and that laid down with extreme accuracy, is what is required, and this has been obtained in the accompanying illustrations.

* * * * * * *

It is also instructive to draw the adiabatic curve, as above stated, in illustrating the changes which would occur could the same quantity of steam be worked in a non-conducting cylinder, and all wastes by heat exchange between steam in the engine and the metal of the cylinder thus be avoided. This would also show, by its departure from the saturation curve, with which it would be coincident at its beginning, the amount of thermodynamic condensation—that produced by conversion of internal energy into the work of adiabatic expansion.

These methods, and the results of their application to a few specially interesting and typical cases, will be illus-

* See Cotterill, second edition. This system was referred to by the writer in the discussion of the paper on the Milwaukee pumping engine, where the question of best methods of combining multiple-diagrams came up (*Transactions* American Society of Mechanical Engineers, Vol. XV).

† For an example of this application see Manual of the Steam-Engine, Vol. I, pp. 406, 407.

trated in the following examples, each of which appertains to a familiar and important class of steam-engines. They are especially instructive, as applied to the multiple-cylinder engine, in which the action of heat transfer and of heat transformation has hitherto remained somewhat obscure, in the absence of such studies of the facts of their operation, cylinder by cylinder. In this application it will be noted that the saturation curve for the combined diagram must usually be discontinuous, as only absolute equality of clearance and compression and of steam condensation can give perfect continuity.

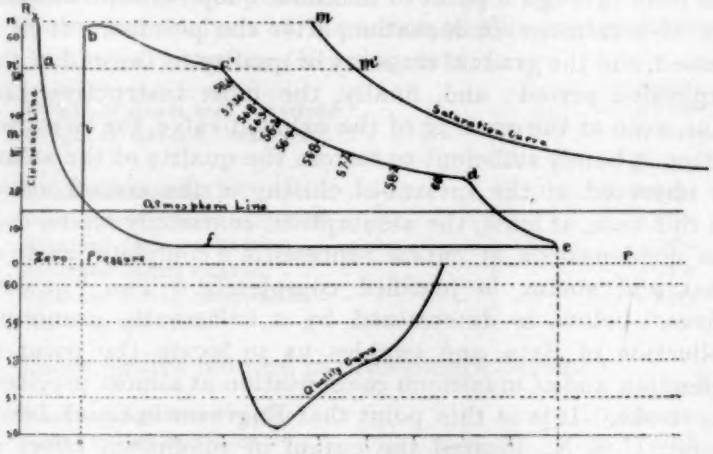

FIG. 1.—Single-valve engine diagrams.

Fig. 1 presents the diagrams from a small, plain slide-valve engine, of 6-inch diameter of piston, and 8-inch stroke; cut-off set at three-tenths, making 208·4 revolutions per minute, and consuming 39·7 pounds of steam per horse-power per hour. The compression line of the indicator diagram is carried up to the steam line to determine the quantity in the clearance spaces, and the amount admitted to cut-off; and the saturation curve for this weight of steam is laid down at the right of the diagram, in such manner that the co-ordinates of the expansion line of the latter and those of the saturation curve shall coincide in magnitude in measuring the varying pressures, and shall

have the proportions of volume of mixture to that of the fluid, when completely vaporous, on the horizontal scale. Below, with its corresponding ordinates in line with those of the indicator diagram, is the "quality curve," exhibiting the variation of quality of steam, with progressing expansion, from the point of cut-off to the end of the expansion period, outside which range this variation cannot be traced on the diagram.

The interesting facts brought out by the comparison of the expansion line of the diagram with the saturation curve of the charge, are the extensive initial condensation, the passage of the fluid through a point of maximum depreciation of quality, of maximum condensation, after the point of cut-off is passed, and the gradual recovery of quality to the end of the expansion period; and, finally, the most instructive fact that, even at the opening of the exhaust-valve, the re-evaporation is barely sufficient to restore the quality of the steam as observed at the instant of closing of the cut-off valve. In this case, at least, the assumption, commonly made, that the condensation at cut-off represents a complete waste of heat and steam, is justified completely. The "quality curve," below, is determined by a sufficiently numerous collection of data, and enables us to locate the point of inflection and of maximum condensation at almost precisely 0·4 stroke. It is at this point that Engineer-in-Chief Isherwood, U. S. N., located the cut-off of maximum effect in engines of this class and in marine engines of the older types. The condensation at cut-off is here 42 per cent., increasing from cut-off at 0·3 stroke, to the maximum, 44 per cent. at 0·4 stroke, and then decreasing, by re-evaporation, to 40 per cent. at the end of the expansion period. The varying speed of piston, and changing temperatures of the gradually uncovered surfaces of the cylinder wall produce a curious wave in the quality curve, and this may be used to obtain approximate measures of temperatures of metal along the cylinder, and of rate of heat-transfer between metal and steam.*

* It will be noticed that the atmospheric line is set at a barometric pressure of 14·42 pounds per square inch. This comes of the fact that the engine is operated at an elevation of several hundred feet above the sea-level.

This illustrates the behavior of an unjacketed cylinder, and the small size of the machine, by exaggerating the action of the metal upon the steam, permits its illustration much more strikingly than would diagrams from an engine of large size.

It is seen that only about 5 per cent. of the total internal waste occurs, in this case, after the close of the cut-off valve. It is further to be especially noted that the steam lost up to the point of cut-off is not re-evaporated in time to do work upon the piston; but that it is necessarily all re-evaporated after the exhaust-valve opens, and during the return stroke of the piston.

A thermal analysis of the action of this engine, in regular operation, gives the following data:

	Pounds.
Weight of steam used per stroke	0·0126
Weight of steam in clearance	0·00165
	B. T. U.
Total heat supplied	12·857
Loss to metal during admission	5·5114
Returned during expansion	1·3586
Returned during exhaust	3·0365
Returned during compression	0·2973
Waste by radiation	0·8190

These figures reduced to percentages become:

	Per Cent.
Heat supplied to the engine	100·00
Stored during admission	42·88
Restored during expansion	10·57
Rejected with exhaust	23·60
Restored during compression	2·31
Lost by radiation from exterior	5·39
Transformed thermodynamically	5·25
Rejected untransformed	94·75

The mechanical efficiency of the engine is found to be 71·2 per cent.

The accompanying set of efficiency curves (*Fig. 2*) for varying ratios of expansion, based upon the performance of the engine with 85 pounds pressure, absolute, shows the resultant effect upon its efficiency, where *a*, the lower line, exhibits the varying efficiency of the ideal representative as measured in pounds of steam consumed per hour; *b*, the

added tax due to the frictional or dynamic waste, the cost in steam being superposed upon the first curve, and the waste by external radiation added to give *c*, the third line; while the internal wastes similarly added as accessions to the values of the ordinates, giving *d*, the upper curve, we are enabled to read the final costs of operation, in steam consumed in the actual case, for ratios of from unity to twelve.

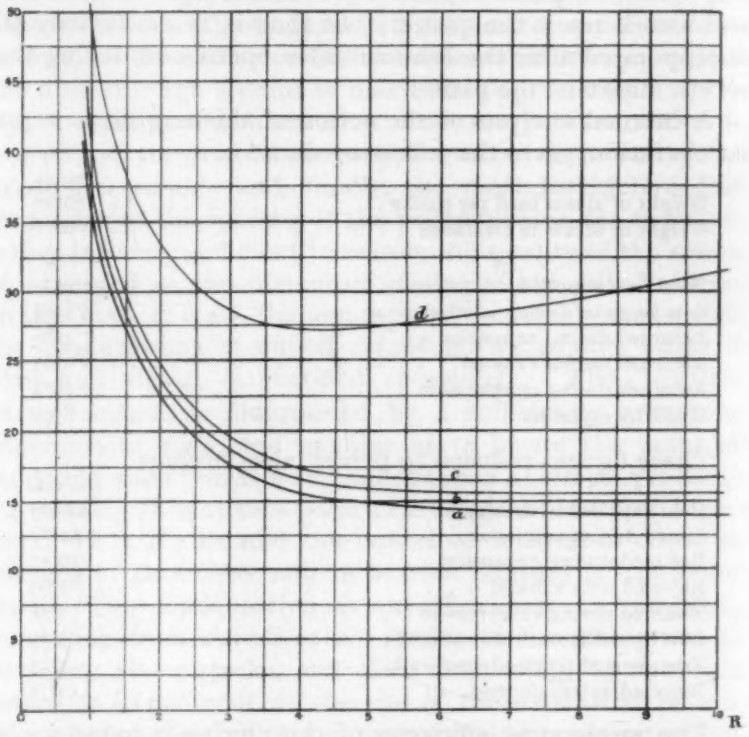

FIG. 2.—Efficiency curves. Small engine; three-ported slide valves.

An examination of these curves shows that this engine, used in connection with a good condenser, with a back pressure not exceeding 4 pounds per square inch, could all extra thermodynamic wastes be extinguished, would have no ratio of expansion for maximum efficiency within the limits here explored; that, the friction losses being added,

the net power would be obtained at minimum cost in steam used at about $r = 8$; that external wastes restrict this figure to about 7; that extreme expansion, when internal wastes come into the account, and maximum total efficiency is sought, cannot exceed 4·5 as the highest ratio for highest "duty." This exhibits very effectively the influence of the several wastes upon small engines of this class. The ideal thermodynamic case would demand but about 14 pounds of steam per horse-power per hour; while the added wastes of the real case, mainly losses by heat exchange between steam and cylinder wall, restrict the expansion to a ratio not exceeding 4½, and raise the steam consumption to 27 pounds at highest attainable duty, doubling the cost of fuel and steam.

* * * * * * *

Fig. 3 illustrates the application of these methods to an engine of highest type of contemporary construction, three cylinders in series, and employing high-pressure steam with a large ratio of expansion. It is the combined diagram of a pumping-engine, beside which are laid down, by the same hand as in the preceding case, the adiabatic for the total steam used, the saturation curve for the working charge, and the hyperbolic line for equal initial volume of charge. The adiabatic here shows the work which would have been performed in a structurally perfect engine of the same cycle, free from extra thermodynamic wastes, by an equal weight of steam from the boiler; the saturation curve exhibits the effect upon the actual charge of working steam of the heat transferred from the jacket; and the hyperbolic curve may be taken as a kind of base line, a standard of comparison for all. The steam supplied is taken as containing less than 2 per cent. water. The figures on the margin of the indicator diagram, in each case, are those of quality of steam.

The saturation curve is here discontinuous, for the reasons already given; the other curves are continuous. All follow the same general trend; they coincide at about the middle of their length and there cross, separating slowly

to the end, but are never far apart at any point. The hyperbolic line is the most nearly approximate to the path of the expansion lines of the diagrams given by the indicator. The departure of the saturation and adiabatic curves at their upper limits measures the proportion of jacket steam, which is included under the latter, but not under the former, since it is desired to exhibit, by the standard given by the saturation curve, the heat flow between working charge and jacket steam, and the variation of quality of the working steam. The zero line of pressure is here 14·5 pounds below atmospheric pressure, as shown by the barometer, properly corrected, at the time of the trial at which these diagrams were taken. The diagrams, on the whole, are remarkable for the exceptional fulness of the actual, as compared with the ideal total-work diagram, for the small amount of initial condensation, for the uniformity of this condensation in the several cylinders, and for the minute loss by drop of pressure between cylinders. The engine itself is remarkable for the smallness of its clearance volumes, the promptness of cut-off, the effectiveness of its jacketing, and the general excellence of design, which enables the ideal to be so nearly approached. The low back pressure is one of the most noticeable points to be observed in this case. The most essential quantities are inscribed on the diagram in *Fig. 3*, which may be studied as an unexcelled approximation to that perfect distribution and utilization of steam which the engineer is constantly seeking.*

Computing the efficiency of the ideal representative case for this engine, and the wastes of the real engine, and comparing them with the results of test, the figures given in the succeeding table are obtained. The wastes are computed for the low-pressure cylinder, and the assumption is made that all work is performed in that cylinder. The dynamic waste is taken, at the usual rating of the engine,

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* An account of this engine is given by the writer in the paper "On the Maximum Economy of the Contemporary High-pressure Steam-engine;" *Transactions* Am. Soc. Mechanical Engineers, 1893.

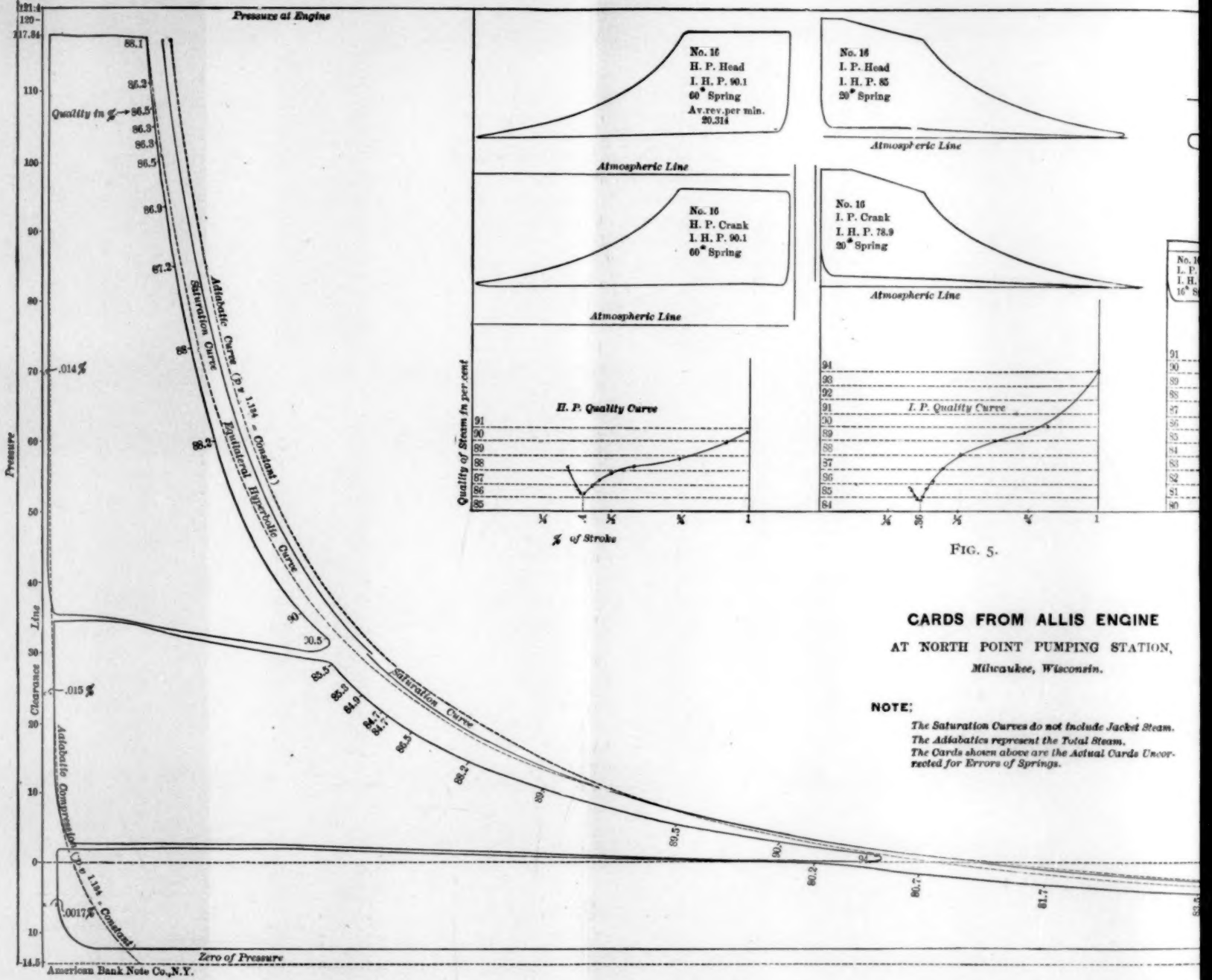


FIG. 5.

CARDS FROM ALLIS ENGINE

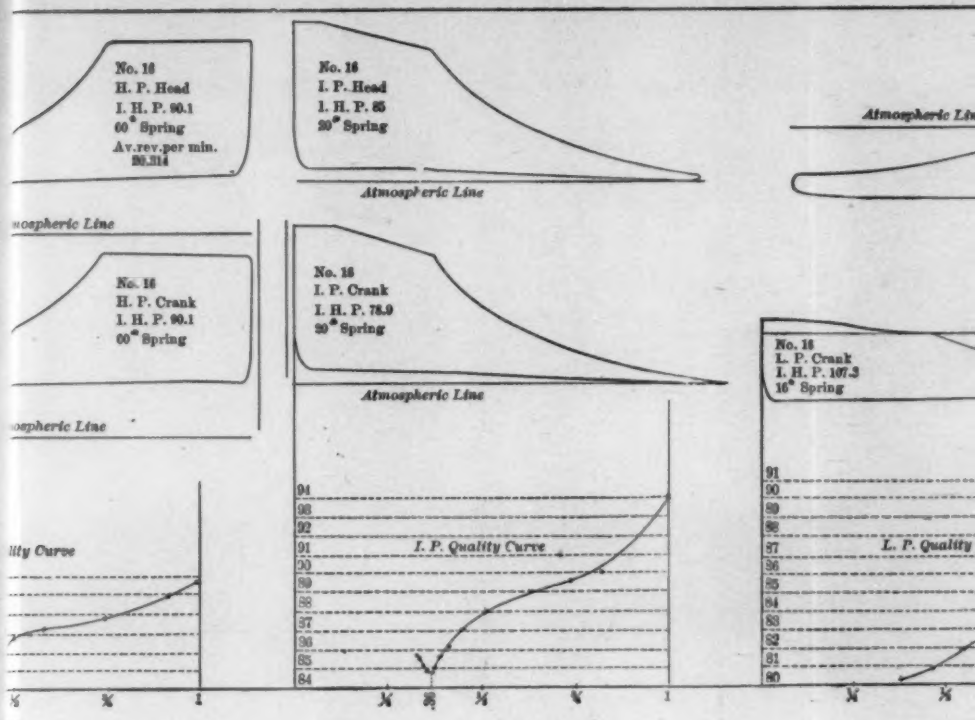
AT NORTH POINT PUMPING STATION,

Milwaukee, Wisconsin.

NOTE:

The Saturation Curves do not include Jacket Steam.
The Adiabatics represent the Total Steam.
The Cards shown above are the Actual Cards Uncorrected for Errors of Springs.

FIG. 3.—Combined multiple-cylinder diagrams.



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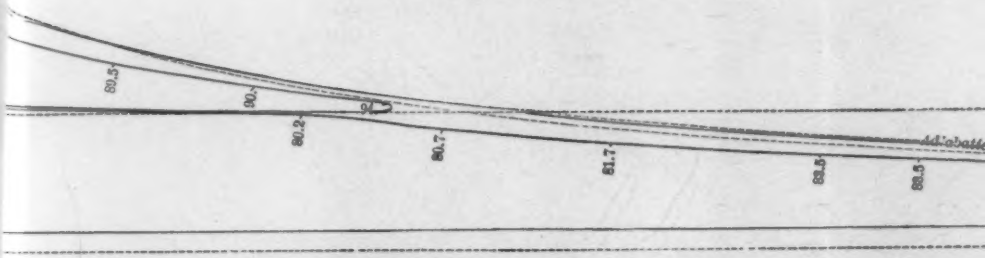

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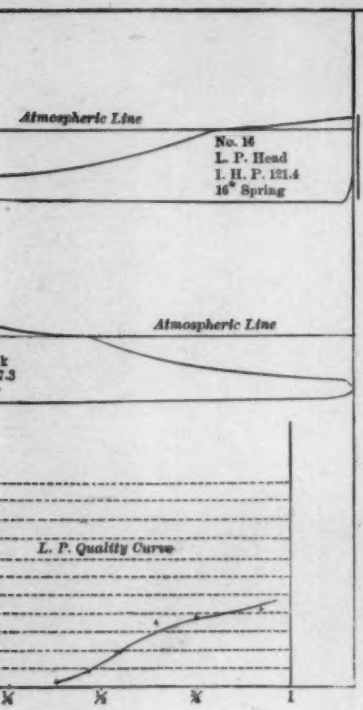
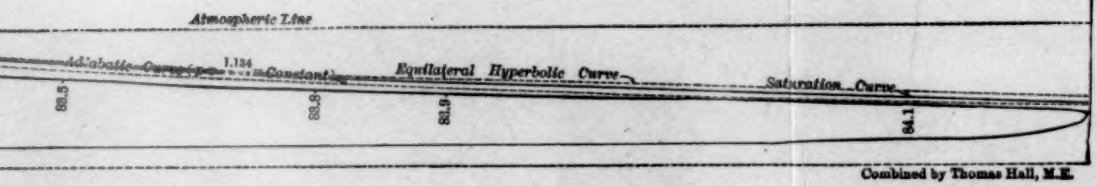


The accompanying plate presents a very accurately-constructed set of combined average diagrams, corresponding very closely with the mean for the trial and with the Thermal Analysis, Appendix D, as prepared for the writer by Mr. Thos. Hall, and with the appropriate saturation-curve for the working steam and the adiabatic expansion-line for the total steam per stroke, laid down for comparisons. There are also given copies of a set of the separate mean indicator diagrams, with the curves deduced from each, exhibiting the varying quality of steam throughout the stroke in each cylinder.

In the first diagram the varying departures of the expanding masses of steam from the dry state are beautifully shown by the separation of the expansion-lines of the diagram from the saturation-curve. The breaks in this curve are due to the differences in clearance volumes and compression in the several cylinders. The adiabatic shows the limit of complete utilization of steam and the total loss of effect by internal wastes. The hyperbolic curve also serves for further comparison, and shows how far the actual deviates from the hyperbolic expansion curve. The distribution of power and adjustment of expansion between the cylinders is well exhibited, as well as the varying heat-flow between steam and cylinder-wall with progressing expansion.

The other diagrams illustrate an especially interesting point—the passage of the point of cut-off in the high-pressure cylinder before cylinder-condensation ceases, as shown by the cusp in the high-pressure quality-curve, and to a less extent in the intermediate cylinder. It does not appear in the low-pressure diagram. Each, in order, shows this more and more rapid and extensive restoration of heat from water to steam, after cut-off, and the final drying of the working-charge, by heat received from the jacket, throughout the whole length of the line on the low-pressure diagram.

Measuring the ideal diagram between the adiabatic expansion and compression lines, we find the real diagram to have 80.53% of its total area. Otherwise stated, the losses by condensation and drop in the engine, as constructed and operated, amount to 20% of the available energy of the steam supplied.



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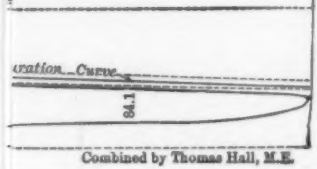

Combined by Thomas Hall, M.E.

as 10 per cent. of the delivered power; the internal heat wastes are computed by the formula*

$$c = a \frac{\sqrt{r\,t}}{d}$$

in which a is taken, as in the Sandy Hook experiments, as 4, and $r = 19{\cdot}55$, $t = 2{\cdot}96$;

$$c = 4 \sqrt{\frac{2{\cdot}23 \times 2{\cdot}96}{74}} = 0{\cdot}13932$$

External wastes of heat are taken as 0·5 B. T. U. per square foot of exterior surface, and per degree difference between external and internal temperatures:

COMPARISON OF IDEAL AND REAL ENGINES.

Size of engine	28 + 48 + 74 × 60 inches.
Real ratio of expansion	19·55
Mean effective pressure, ideal case	25·00
Mean effective pressure, real, computed	18·99
Mean effective pressure, real, observed	21·80
I. H. P., ideal	660
I. H. P., real, computed	567
I. H. P., real, observed	573·9
D. H. P., ideal	660
D. H. P., real, computed	501
D. H. P., real, observed	520·9
Dry steam, per I. H. P. per hour, ideal	8·90
Dry steam, per I. H. P. per hour, real, computed	11·73
Dry steam, per I. H. P., per hour, real, observed	11·68
Heat, B. T. U., per I. H. P. per minute, ideal	167
Heat, B. T. U., per I. H. P. per minute, real, computed	220
Heat, B. T. U., per I. H. P. per minute, real, observed	217·6

The curves of efficiencies (*Fig. 4*) illustrate the action of this engine very perfectly. The lower curve is that of steam consumption of the ideal case, the next the dynamic wastes, the third is the external thermal loss, and the upper is that of the internal thermal wastes, each quantity being superposed on the preceding in such manner that the ordinates of the highest curve give the computed, and approximately the real, steam-consumption of the engine at the ratios of expansion corresponding to their location. It is

* Manual Steam Engine, Chapter V.

seen that the real engine has a maximum efficiency, thus measured, at a ratio of expansion of about 20, the ratio actually adopted by the builders. The fact that its record is the best yet registered is good evidence that the conclusion thus derived is substantially correct. The upper dotted line in the diagram is that representing the internal thermal wastes of the engine, as computed on the assumption that all work is done in the low-pressure cylinder, converting the machine into a simple engine. It exhibits the wide difference in final efficiency produced by the cascade

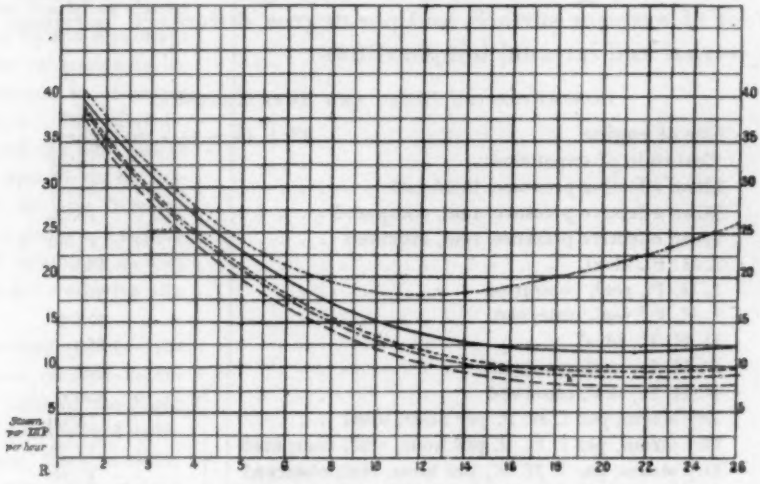

FIG. 4.—Efficiencies of triple-expansion engine.

action of the multiple-cylinder engine, while the effect on the best adjustment of cut-off is brought out very strikingly also.

The fac-similes of the diagrams taken from the several cylinders which are combined in the preceding illustration, and the quality curves which are obtained from them, are given on *Fig. 5*. The engine has steam cylinders, 28 inches, 48 inches and 74 inches in diameter, and is of 60 inches stroke of piston, carrying 120 pounds steam-pressure at the steam-chest, and making 20·3 revolutions per minute when giving a duty of 154,448,000 foot-pounds per 1,000 pounds of dry steam supplied. The set of diagrams here given repre-

sents a very fair average for that engine, but is simply illustrative of the subject of this paper, and is not selected for any other purpose. The essential data are inscribed on the diagrams. Below each pair is placed the "quality curve" obtained as their average. These quality curves exhibit beautifully the action of heat-exchange in the successive elements of the series, and the effect of the jacket in modifying the extent and rate of transfer as illustrated in the simple unjacketed engine first considered.

In the high-pressure cylinder the same general method of heat-exchange is seen, but the condensation ceases more nearly at the point of cut-off than in the first case. The cusp is no less certainly present, but its extent is reduced by the action of the jacket, which, however, is not very active in the high-pressure cylinder usually. In this respect this case is exceptional, as the initial condensation is here less than 12 per cent. The same wave in the line between the point of the cusp and the terminal of the curve is here seen that was observed in *Fig. 1.* The curve, as a whole, has the same form as in that figure, but its variations of curvature are less extensive, and the heat-exchanges, therefore, correspondingly less serious in reduction of the efficiency of the engine. The same fact is here seen relative to the change of "quality" between cut-off and exhaust. The total change is from 88 to 90·5, notwithstanding the effectiveness of a jacket which held down the initial condensation to 12 per cent. These facts indicate the small amount of heat transferred from jacket to working steam in the high-pressure cylinder, and the correctness of the assumption that the quantity of condensation at cut-off measures the internal waste with substantial accuracy. Correcting for the concealed effect of thermodynamic condensation, here amounting to about 8 per cent., it would appear that the jacket and re-evaporation together transferred heat enough to the charge to improve its quality about 10 per cent. in the absence of adiabatic condensation. The cut-off here takes place at one-third stroke; the maximum condensation occurs at four-tenths, precisely as in the unjacketed engine.

The intermediate cylinder exhibits the cumulative effect of jacket action in the reduced extent of the cusp, its earlier occurrence after cut-off, and the larger improvement in quality of steam between cut-off and exhaust, which here amounts to above 8 per cent. The same wave is seen as in the preceding cases, indicative of variation of relative velocities of piston and of heat-exchange. Cut-off here takes place at 0·34, and the cusp is found at 0·36. Thermodynamic condensation should increase the waste from the 13 or 14 per cent. at cut-off to about 18 per cent., while the actual change is an improvement of 9 per cent., showing jacket-action and re-evaporation to have transferred to the steam nearly 15 per cent. of the total heat energy in the engine. The curve for the low-pressure cylinder shows still further progress in the same direction. The cusp has disappeared, the steam is continuously dryer as the piston moves from cut-off to the end of stroke, and the improvement in quality amounts to about 10 per cent., notwithstanding a further thermodynamic condensation of about 5 per cent. Jacket action is more effective in the intermediate than in the high-pressure cylinder and receiver, and still more so in the low-pressure receiver and cylinder. In this engine, taken as a unit, the adiabatic condensation is about 17 per cent., and the jacket holds down the initial condensation to 12, the final to 8, counteracting, at the same time, the adiabatic condensation, and thus giving a total heat-transfer sufficient to vaporize a net 20 per cent. at final exhaust, of which 9 per cent., as measured, comes from the jacket itself, and the remainder from the heat-store previously taken into the cylinder walls. This latter quantity, 12 per cent. at the start, is thus probably largely re-transferred before exhaust, a fact apparently indicating the complete drying of the surfaces of the cylinders previous to the opening of the exhaust-valve on the low-pressure cylinder.

The final net result may be stated thus: The supply of 9 per cent. of the steam to the jackets, in this case, produced a reduction of initial condensation, from a probable 30 per cent. at the beginning of expansion, to 12, and counteracts thermodynamic condensation to the extent of about 9 per

cent. by transfer of heat to the working steam. Thus, checking thermodynamic condensation results in the restriction of internal wastes by about double the amount of heat so expended through the intrinsically wasteful action of the jacket.

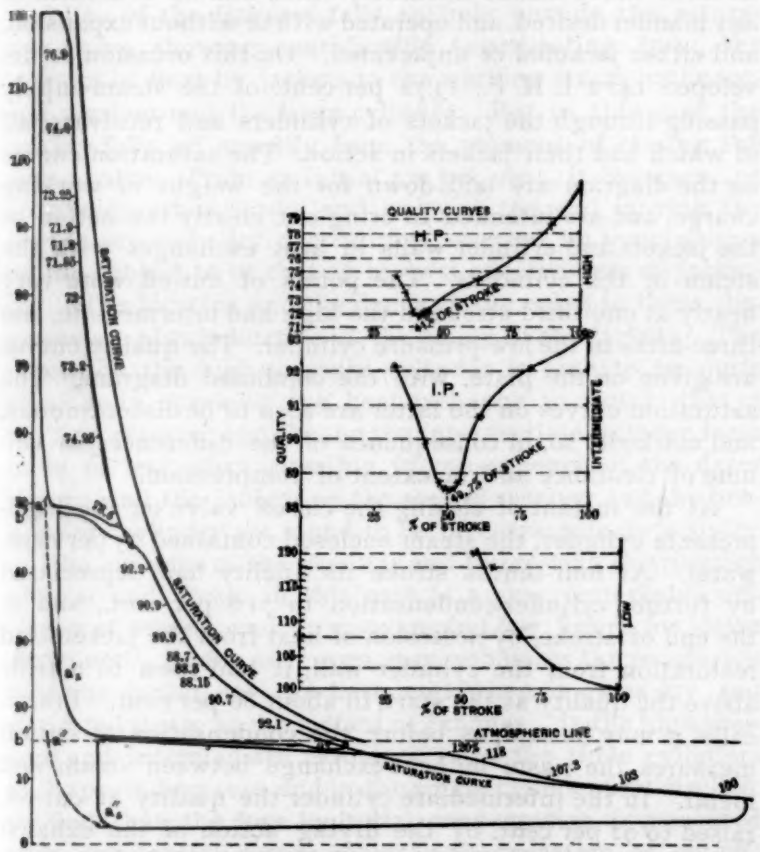

FIG. 6.—Quality-curves of triple-cylinder engine.

The next example is, in some respects, still more interesting, novel and instructive. The combined diagrams (*Fig. 6*) are obtained from the Experimental Engine of Sibley College, Cornell University, and represent the distribution and quality of steam in its passage through the engine,

when the cost of the horse-power was that of 13·3 pounds of dry steam per hour, perhaps the lowest figure ever attained on an engine of such small size and power. This engine has cylinders 9 inches, 16 inches and 24 inches in diameter, and a stroke of piston of 36 inches. It is arranged as three independent machines, which can be combined in any manner desired, and operated with or without expansion, and either jacketed or unjacketed. On this occasion it developed 140·2 I. H. P., 13·72 per cent. of the steam-supply passing through the jackets of cylinders and receivers, all of which had their jackets in action. The saturation curves on the diagram are laid down for the weight of working charge, and are intended to bring out clearly the action of the jackets and cylinder walls in heat exchanges with the steam in the cylinders. The points of cut-off were very nearly at one-third stroke in the high and intermediate, and three-fifths in the low-pressure cylinder. The quality curves are given on the plate, with the combined diagram. The saturation curves on the latter are seen to be discontinuous, and markedly so, in consequence of the differences in volume of clearance and in extent of compression.

At the instant of closing the cut-off valve on the high-pressure cylinder, the steam enclosed contained 25 per cent. water. At four-tenths stroke its quality had depreciated by further cylinder-condensation to 71·8 per cent., and at the end of stroke, by accession of heat from the jackets and restoration from the cylinder wall, it had risen to a trifle above the quality at the start, to about 80 per cent. Practically, it may be said, as before, the condensation at cut-off measures the waste by heat-exchange between steam and metal. In the intermediate cylinder the quality at cut-off, raised to 92 per cent. by the drying action of the exhaust period of the high-pressure cylinder and of the receivers and their jackets, becomes 88 per cent. at half stroke, as a minimum, and then rapidly improves to the end of the stroke, where it is 93 per cent. Here, again, it is found that the waste is measured by the condensation at cut-off. It will be noted that the saturation curve for the intermediate cylinder falls inside the line of that for the high-pressure,

and that the indicator expansion-line falls outside, the two lines being more closely approximated in the case of the intermediate than in that of the high-pressure cylinder.

The low-pressure cylinder presents the most singular departure from the usual case. The saturation curve falls still further inside the lines for the other cylinders, the expansion line of the diagram falls entirely outside the saturation curve, showing considerable superheating from the transfer of heat by jackets to the working steam in the second receiver and the large cylinder. But in this case the quality falls off steadily from the moment of closing the steam-valve. From an initial 120 per cent., it becomes 107 at three-quarters stroke, and unity at the end, leaving the engine precisely dry, a condition asserted by some writers on the subject to be that of highest effectiveness of jacketing. The location and the depth of the cusps in these diagrams are also indicative of the action of the jackets. The jacket on the high-pressure cylinder is seen to be quite effective in checking the heat-exchange to metal; that of the first receiver and that on the intermediate cylinder seem to be of less effect, possibly in consequence of the dryer steam; and the jackets on the second receiver and the low-pressure cylinder are found to be of extraordinary activity.

The outcome of the peculiar and interesting distribution of heat and steam in this case is a very remarkable efficiency of engine, and an unexampled low figure for steam consumed. So far as it goes, it corroborates the conclusion that the jacket does its best work when it gives dry and saturated steam at the instant of exhaust. In the high-pressure and intermediate cylinders, as in the three cylinders of the preceding case, and in the single cylinder first studied, we find that the loss by initial condensation is measured with substantial accuracy by the condensation at cut-off; but in the low-pressure cylinder in the last example, the large flow of heat from the second receiver and third cylinder jackets sensibly modifies this result. The total condensation in the jackets amounts to 13·72 per cent. of the whole steam supply. Of this one-fourth was condensed in the high-pressure jacket, one-twelfth in the intermediate, and

one-third in the low-pressure, while the balance was condensed in the receivers, in the proportion of over three to one in the second. The low-pressure jackets and second receiver take about one-third of all steam sent into the jacket system.

The pair of diagrams (*Figs.* 7 and 8), with their respective quality curves, illustrate the effect of a process of reduction of internal waste which has been often proposed, but, perhaps, never before actually attempted. It involves the regulation of the engine by variation of the compression

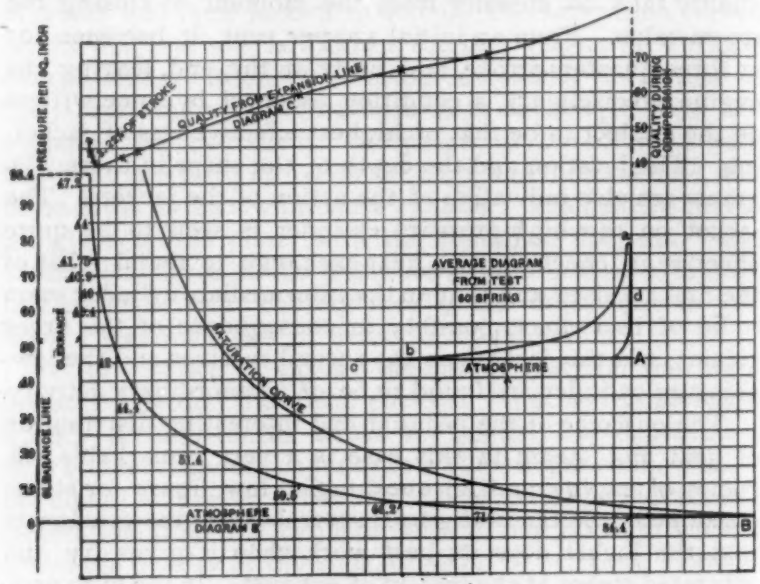

FIG. 7.—**Heat exchanges with large expansion.**

line, instead of, as usual, by the adjustment of the ratio of expansion to the momentary variations of load. The question to be settled by the examination of these diagrams is simply whether high compression will reduce the initial condensation, and thus effect economy, where it is well known that high expansion causes loss.

* * * * * * *

The same cusp which has been previously observed is here distinctly exhibited. With the extreme expansion

here adopted, it is also clearly seen that re-evaporation not only restores the initial quality of the steam, but greatly improves it, in spite of the resisting action of thermodynamic condensation; and the quality varies from 47 at the instant of closing the steam-valve, to 40 at one-thirtieth stroke, to 66 at about half stroke, and to 84·4 per cent. at the end. About two-thirds of the condensed steam is re-evaporated in the expansion period. In the second illustration, the same power is obtained from the engine, and at the same speed, the brake being adjusted to the same load, and

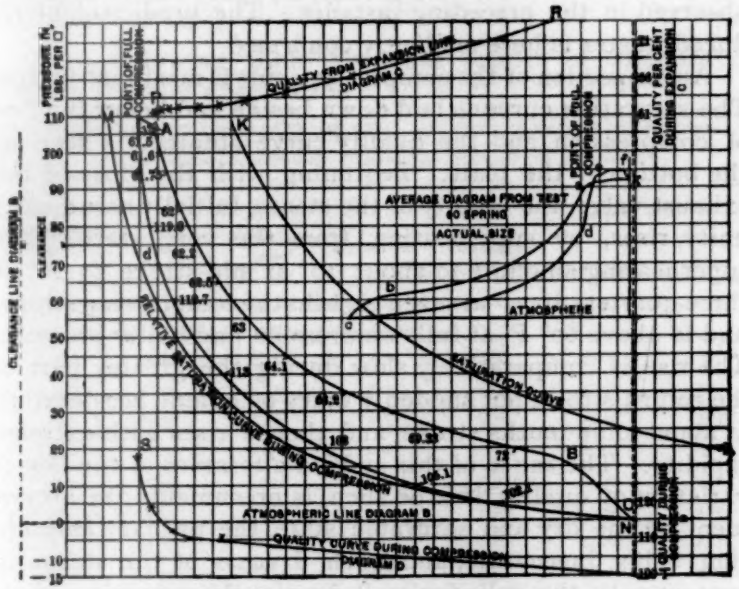

FIG. 8.—Heat exchanges with large compression.

the compression and expansion lines are so adjusted as to give the diagram shown, at the power required. Compression is carried up to boiler pressure, and the expansion line made what is found desirable to give the power considered likely to prove a minimum, or nearly so. The effect upon cylinder condensation is seen to be marked, and precisely what had been anticipated. The cusp has disappeared, and the quality of the expanding steam now rises steadily from the first, from about 60 to above 70 per cent., in the course

of the period of expansion. The condensation has been reduced from 53 to 38 per cent.; the improvement in quality amounts to 14 per cent. at the beginning of expansion, and the two curves exhibit equality at about three-quarters stroke, while the first of the pair is better by over 10 per cent. at the end. The gain of nearly 30 per cent. in the reduction of initial condensation is the important feature; but the comparatively small re-evaporation during expansion is singular and interesting, especially when it is compared with the large re-evaporation observed in the preceding instance. The prediction of reduced wastes is here evidently confirmed.

An inspection of the compression side is most instructive. The saturation curve is laid down beside and below the line of compression, and the quality curve obtained is seen at the bottom of the plate. Beginning with the close of the exhaust-valve, the quality of the steam, initially assumed as unity, rises, by superheating, from the very start. This superheating amounts to about 10° at mid-stroke, to 20° at three-quarters, to 25° at seven-eighths the compression stroke, and to above 60° F. at full compression and boiler pressure. The rise is comparatively slow during the greater part of the return stroke, but suddenly takes on a rapid acceleration at about nine-tenths stroke, and thence rises with extreme rapidity. The cause of this sudden alteration of the law of variation of quality, if it be such, is presumably the attainment of the dry and saturated state, the primary assumption being inaccurate, and such dryness of the steam in contact with the cylinder wall, previously remaining more or less wet, that heat can no longer readily be transferred to the metal, and the whole work of compression is effective by transformation of dynamic into thermal energy. It is this earlier transfer of heat of compression to the metal, and the resultant dryness of surface, with increased temperature, which, as was anticipated, gives the economy seen on the steam side after the opening of the induction-valve.

* * * * * * *

The following are the principal elements of the performance of this engine under the usual conditions of operation

and at various ratios of expansion, both as computed by the now familiar methods pursued in the Sibley College laboratories, and long ago introduced by the writer, and as observed in formal trials.* The internal wastes are computed from the expression

$$c = a\sqrt{rt}$$

in which a is taken as 22·5 per cent. There were noted:

Boiler pressure, by gauge, pounds per square inch	100
Revolutions per minute	86
Quality of steam at engine, per cent.	98
Back-pressure, pounds per square inch	5
Friction of engine, per horse-power	7·25

The following table gives the results of computation beside those of observation:

ECONOMICS OF IDEAL AND OF REAL ENGINE. (9 IN. × 36 IN.; 86 REVS.)

Expenditures in Pounds of Steam per Horse-Power per Hour.

Ratio of Expansion.	Ideal.	Frictional Loss.	Radiation.	Initial Condensation.	Real Engine.	
					Computed.	Total Observed.
	Lbs. Steam.	*Lbs. Steam.*	*Lbs. Steam.*			
1	32·91	1·73	·267	7·62	42·63	—
2	20·50	1·75	·268	6·68	29·18	29·1
3	16·70	1·78	·268	6·70	25·45	24·6
4	15·11	1·80	·270	7·01	24·19	23·1
5	14·21	1·83	·271	7·40	23·71	22·6
6	13·52	1·86	·272	7·70	23·35	22·8
8	12·67	1·98	·275	8·27	22·20	23·7
10	12·22	2·12	·280	9·10	24·08	24·0
12	11·90	2·37	·291	9·50	24·06	24·5
15	11·70	2·71	·305	10·30	24·92	25·5
20	11·61	3·06	·331	12·00	27·00	28·0

The engine trials showed a slightly more rapid gain in the earlier cuts-off, and a greater waste in the later, than were computed; but the two sets of figures are closely accordant throughout, indicating the practicability of securing a measure of the constants, in the expressions for

* Manual of the Steam Engine, Vol. I, Chaps. IV, V.

wastes, by a single trial at any convenient and usual load, and thus a clue to the behavior of the engine at all loads. This fact is of great importance where questions of relative efficiency and costs arise in adjusting sizes and steam dis-

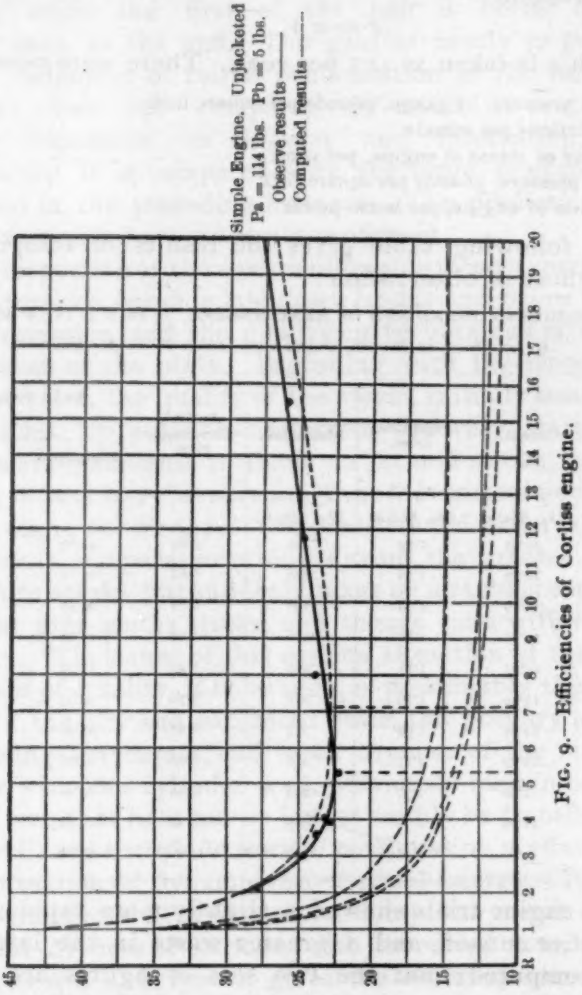

FIG. 9.—Efficiencies of Corliss engine.

tributions of engines to changed or to very variable loads. The two sets of results, computed and observed, are well shown in *Fig. 9*, arranged like the first presented herewith. It is seen that the maximum efficiency is attained in the

computed case at a ratio of expansion of 7, while the engine actually does its best work at about 6. This indicates a greater proportional initial condensation at cuts-off near the beginning and the end, and less at the intermediate portions of the stroke than the assumed hyperbolic law of our formulæ would give; and this conclusion is confirmed by many experiments on a great variety of engines and under very various conditions of operation.

The introduction of high compression in regulation—which was long since proposed by the writer*—as experi-

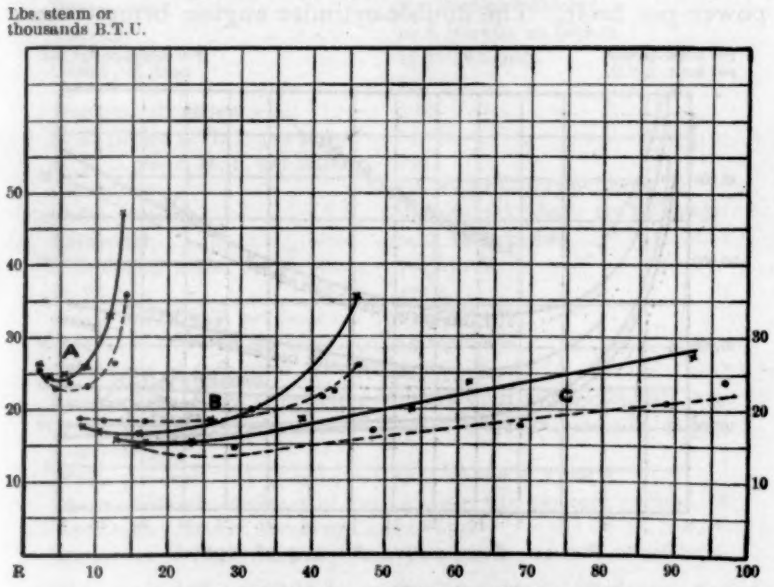

FIG. 10.—Efficiencies of multiple-cylinder engine.

mentally tested by Prof. J. H. Barr, whose work is illustrated above, would presumably improve the action of the engine economically, by depressing the whole upper line of the last diagram and straightening it, and especially by giving it an improved location at the end nearest the commencement of the stroke.†

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* *Transactions* Amer. Soc. Mech. Engineers, August, 1881.

† This particular set of experiments, although verifying the predicted effect of the system upon the heat-exchanges and wastes within the cylinder, did not give evidence of a probability that, on the whole, important gains could be thus secured on this size and class of engines.

As illustrating the modification of efficiencies in this engine produced by compounding, *Fig. 10* presents an interesting set of curves of efficiency obtained from the Sibley College experimental engine by Mr. H. K. Spencer, following the methods which have been customary with the writer in such work, and under the conditions of steam-pressure and back-pressure already described. The simple engine does its best work at ratios of about 4 and 6, unjacketed and jacketed, respectively, the minimum cost in steam being 23 pounds steam, about 23,000 B.T.U. per horse-power per hour. The double-cylinder engine brings these

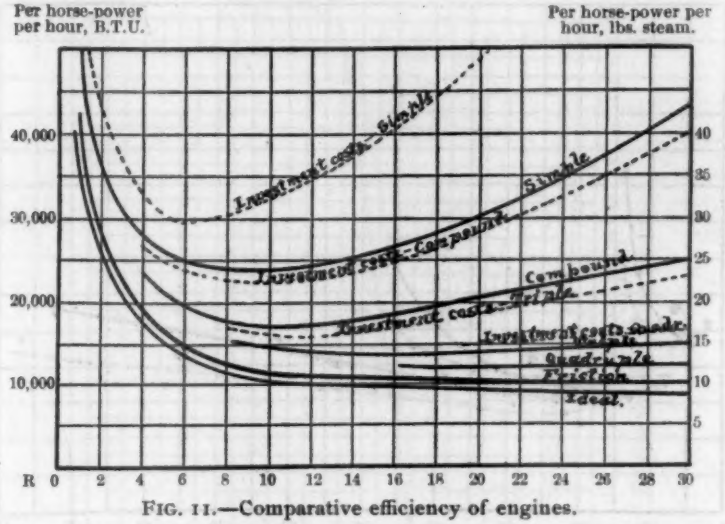

FIG. 11.—Comparative efficiency of engines.

figures up to 12 and 17 for the ratio of expansion, and down to 16 and 18 pounds of steam, and exhibits the anomaly—in this instance the idiosyncrasy—of doing its best work with cylinders and receiver unjacketed at the lower, and the reverse at the higher ratios of expansion. The triple-expansion engine performs its highest duty unjacketed at 20 expansions, jacketed at 22, and at an expenditure of, respectively, a trifle above 15 and 13·3 pounds of steam per hour per horse-power. In the figure the curves *A* are those obtained from the engine when the high-pressure cylinder is worked alone as a simple engine, jacketed and unjacketed;

B is the set of curves obtained from high-pressure and intermediate, working as a compound; and *C* is the set representing the machine as a whole, jacketed and unjacketed, working as a triple-expansion engine, but with only 125 pounds pressure, instead of 175, as originally designed.

* * * * * * *

The following are the data obtained at present when working as last indicated, and under best conditions:*

Cylinders	$9 + 16 + 24 \times 36$ inches.
Piston-rods	2·31 inches diameter.
Vacuum	10·8 pounds, 22 inches.
Jacket water	13·72 per cent.
Total I. H. P.	140·2
Mechanical efficiency	0·88.
B. T. U. per I. H. P. per hour	14,160.
B. T. U. per I. H. P. per minute	236.
Clearances	7·6, 8·93 and 9·35 per cent.
Boiler pressure	pounds, 125 (abs.); 110 by gauge.
Barometer	29·4, 14·42 inches.
Condensing water, per lb. steam	19 pounds.
D. H. P.	123·4.
Steam per I. H. P. per hour	13·3 pounds.
Steam per D. H. P. per hour	15·1 pounds.
Total ratio of expansion	13·83.

Pressures (absolute) at cut-off, 131, 43, 13·5; at release, 43, 14·5, 2·5.
Jacket water, per cent., 26·4, 7·05, 28·1 in cylinders; and 9·85, 34·6 in receivers.
Work, per cent., 1, 1·33 and 1·675, in cylinders 1, 2 and 3.
Thermodynamic efficiency of Carnot cycle, 24·7 per cent.; actual, 18 per cent.; ratio of actual to Carnot, 0·73.
Water-rate of ideal Rankine cycle, 9·6 pounds; ratio to actual, 0·72.

The final effect of the wastes here specially considered, however, can only be discovered in all their bearings when the total variation of costs of power in the engine, with variation of its output, are studied together.

In *Fig. 11*, which concludes this series, are graphically exhibited all the elements which finally determine the costs and profits on the use of the engine, in such manner as to give a clue, if not an exact measure—such as is probably often possible to secure—and thus to enable the engineer

* *Transactions* Amer. Soc. Mech. Engineers, 1894; "Theory of the Steam Jacket," Discussion, p. 879.

to ascertain just how much improvement in economy and efficiency of engine it is financially practicable to demand, what efficiency it will pay to seek. In these curves the variations of each element in the problem are shown by a curve, the ordinates of which are in each case measured from the curve immediately below; in other words, the costs of power are shown in steam or fuel or money, either unit of measure being equally available, provided all are reduced to equivalence. The lowest line is the curve of steam expenditure, and is the ideal case, the purely thermodynamic case, as computed by Rankine's method. The second curve, superposed upon the first, is that which exhibits the added cost of friction of engine in the same unit of measure. The curve marked "simple" is one of which the ordinates, measured down to the friction curve, are proportional to the cost of the wastes in the simple engine by cylinder condensation and leakage, and, by conduction and radiation, the thermal wastes other than thermodynamic. The highest curve is the measure in the same way, its ordinates being measured down to the last-named curve, of the investment costs, which include the interest on first cost, the charges for insurances, rents and other purely financial charges for capital employed in the purchase, installment and preservation of the machine.

It is assumed that the compound engine will approximately divide the cylinder wastes of the simple engine by two, that the triple-expansion engine will have one-third the wastes of the simple, and that, generally, the multiple-cylinder engine will, if properly employed, approximately reduce these internal wastes in the proportion of the number of cylinders employed. This being assumed for an approximation, the curves marked "compound" and "triple" and "quadruple," in full lines, measure, as before, the cylinder wastes of those engines, and the dotted lines, as before, the financial costs of each. The diagram is simply illustrative, but can be easily constructed for any stated case in which the quantities required for its construction can be ascertained, or where any three or four points in each curve can be identified by reference to experiment, or by computation from known data.

The final and essential deductions to be made from this construction are that, while the ideal case, the purely thermodynamic engine, will give increasing efficiencies with increasing expansions indefinitely, the back-pressure not being reached, the introduction of the friction of the engine produces a change, both in the location and the form of the curve, such that, after a time, with increasing expansion, a maximum efficiency is attained, and a minimum cost of power. And, were the curve extended far enough, a point would be found at which the power of the engine would be insufficient, not simply to yield the required power to the belt, but even to turn over the engine shaft alone. With the introduction of internal and other thermal wastes. the maximum efficiency and minimum costs are found at not only a higher figure, but at an enormously reduced ratio of expansion, which, in the case of the simple engine, as here taken, is not far from 8; in the compound, 12; in the triple, 16; and in the quadruple, 22 or 24. When the investment costs are brought into the account, we again have the best ratio of expansion reduced in value; and in the simple engine here taken, it becomes about 5; in the compound, 8; in the triple, 12; and in the quadruple, 16. These figures would vary greatly with the value of fuel and other costs, becoming higher in marine practice than in stationary, for example, other things equal; lower in a coal-mining district than in a country remote from fuel supplies. With coal at $1 per ton, in one case, and at $5 per ton in another, we should probably find the simple engine, on the whole, most desirable, from a financial standpoint, in the one instance, and the quadruple expansion engine the right selection in the other.*

Whatever the location, the conditions of fuel supply or the value of money, the methods here indicated, it has seemed to the writer, may often be found useful in securing the best design and construction of engine, and the highest financial returns on the investment of capital in the provision of power.

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* "Use of Compound Stationary Engines," *Engineering Magazine*, September, 1894.

MODERN THEORIES OF FERMENTATION, WITH NOTES ON THE MORPHOLOGY AND CULTURE OF YEASTS.*

By Dr. Francis Wyatt.

The subject I have chosen to talk to you upon is that of "Germs," those minute living things which are almost inconceivably numerous, and which swarm in endless profusion upon the surface of the earth, and in and beneath the waters.

It is, of course, only natural that infinitely small organisms should enjoy greater advantages than larger ones in the matter of reproduction, because they find food for development more readily, and are more easily carried from place to place. Let me quote two familiar facts as an illustration:

If you allow some spring water to stand in a glass you will notice that it will become green from the growth of small algæ. The germs of these plants were invisible to the eye, but they were either present in the water itself, or were carried into it with minute particles of dust from the air. Again, if you moisten a piece of bread and keep it damp and exposed to the air, a growth of mould will make its appearance. This proceeds from germs of mould fungi derived from the atmosphere.

A very large variety of these germs are extremely common, and have a very wide area of distribution. The general principles of life with them are the same as with higher and larger organisms, and they are, no doubt, similarly affected, though to a less degree, by climatic and other external causes. There is, for example, a very minute fungus, which in some latitudes vegetates on the bodies of living house-flies, and which in other latitudes has never been observed; but on the other hand, the common species

* A lecture delivered before the Franklin Institute, January 10, 1896.

of moulds, such as the *Penicillium glaucum*, are spread all over the world, and can flourish in all climates.

In the present imperfect state of our knowledge of the several species of bacteriæ, it is impossible to make any very precise general statements with respect to the whole of them, but it is safe to say that they are so liberally scattered abroad in every direction, that their appearance at all spots where they find favorable feeding conditions is more than sufficiently explained.

The microscopical investigation into germ life is naturally surrounded by a great many difficulties, and these difficulties can only be surmounted by willing and intelligent students. Sometimes the germs are not present in every smallest spot of earth, air or water, and various devices must be applied to lighten and facilitate the labor of seeking for them. The famous Koch suggested a very ingenious plan which he based upon the fact that gelatine, if combined with some nutrients easily prepared and in a state of solution, becomes a very favorable medium for the development of bacteriæ and non-parasitic fungi. Let us suppose that we are going to examine the air of this chamber. We should draw it very slowly, by means of an aspirator, through a series of glass tubes coated on the inside with properly prepared gelatine, liquefying at a moderate temperature, and becoming stiff when that temperature is lowered. If the inflowing stream is properly regulated, the greater part of the germs which are mixed with the air sink downwards and are caught in the gelatine, where they undergo further development. If the experiment is properly conducted, with a due appreciation of the results desired, and if all disturbing impurities are excluded, quite distinct groups of bacteriæ and fungi will be found in the gelatine after the lapse of a few days, and can be readily seen and counted by the microscope. Each group or colony originated in a germ, or in some cases from an assemblage of germs, which made their way to the particular spot at the commencement of the experiment, and thus the sorting and selection of any particular form of bacteriæ for isolated culture in a subsequent operation become comparatively easy

The two sub-kingdoms of the vegetable world are the flowering plants, or *Phanerogamia*, and the flowerless plants, or *Cryptogamia*, the lowest subdivision of which embraces the *Thallophytes*, having neither leaves, roots, stems nor fibro-vascular tissue. Among the *Thallophytes* have been classed the *Schizomycetes* or *Bacteriæ*, and the *Algæ* and *Fungi*, which include both moulds and yeast.

In very minute forms of life it is difficult to distinguish animals and vegetables from each other, or to select and adhere to any universally applicable definition of species. In the case of the higher plants and animals the line is easily drawn. While the former are able to derive their sustenance from such inorganic compounds as carbon dioxide and ammonia, the latter must have their necessary supply of carbon or nitrogen presented to them in the form of organic compounds. Here, therefore, is a perfectly broad distinction—the plant lives and develops by the assimilation of the elements of carbon dioxide and ammonia, whereas the animal subsists either on vegetable substances or on the bodies of other animals. With the fungi the difficulty of distinction is heightened by the fact that they may, to a certain extent, be said to partake of the nature of both plants and animals; for while they cannot assimilate carbon from inorganic sources, they are able to derive their nitrogenous nutriment from inorganic bodies.

The chemical changes produced during the growth of the *higher* plants result in the building up of complex compounds from the simple ones. The chemical changes involved in the growth and development of animals are the reverse of this, complex bodies being required as nourishment, and being again broken down into simpler ones. The chemical operations of plant life may therefore be regarded as synthetical, while those of animal existence are analytical. The force required by plants, in order to effect the synthesis of their compounds, is probably obtained from the sun, and necessitates a constant absorption of heat. The force exerted by animals in breaking down the complex bodies built up by the plants involves a constant evolution of heat, and thus, as I have said, the fungi occupy the singu-

lar position of combining the vegetable functions of synthesis with the animal functions of analysis.

The *Schizomycetes* or *Bacteriæ* are exceedingly minute bodies, often on the very border line of visibility. They are the cause of putrefaction, as well as of fermentation in the widest sense, such as the souring of milk, the production of vinegar, the decomposition of bouillon, etc. Some species produce disease either in man or animals, or both; some develop pigments, as the red of *Micrococcus prodigiosus*, or the yellow of *Sarcina lutæ;* some cannot exist without free oxygen, and some live for a long time in its absence.

With some species of bacteriæ, as, for example, the so-called "vinegar plant," a gelatinous envelope forms around the organisms at a certain stage of their existence, and an irregular agglomeration ensues, which is termed the zoöglœan formation.

A coccus is a circular or egg-shaped cell. Organisms of this kind are found detached, in pairs, fours, packets and strings. A rod-shaped organism, having two parallel sides, is termed either a bacterium or a bacillus. Formerly the very short rods, such, for example, as those whose lengths do not exceed twice their breadth, were termed bacteriæ, and those of greater proportionate length bacilli; but the two varieties are now frequently classed under the latter head, leaving the term bacteriæ free as a general name for the *Schizomycetes*. These organisms divide only in one direction. If the rod is bent it is known as a *vibrio*, and if of corkscrew shape, a *spirillum*, while, if lengthened into a thread or filament, it is spoken of as a *leptothrix* form, which may be either straight, wavy or looped, the leptothrix itself being straight and showing a distinction between base and apex.

Very frequently, though not invariably, bacteriæ exhibit the power of spontaneous movement, in some cases spinning round or darting forward with great rapidity, in others gently undulating, and in others again moving with either a tremulous or gentle sinuous motion. In many instances they are provided with vibratile lashes or flagellæ, by the action of which the movemnt is clearly produced.

Bacteriæ multiply by fission and by the formation of

endospores, the organism in the latter case showing a highly refractory speck, which gradually enlarges, takes a circular or oval form, and eventually appears to absorb the whole contents of the original cell.

The life history of a large number of bacteriæ may be very aptly illustrated by that of the tiny *Monas Dallingeri*, which, measured cubically, is the seventy-thousand-millionth of a cubic inch. It is a long oval, with one motile fiber. The egg-like body is clear, and, to our means of analysis, structureless; in the minutest speck of liquid thousands may be present. Their motion is quick, definite and graceful. While in full motion a change of form, which is somewhat uncertain, takes place in from a minute to ninety seconds, and then the motion becomes slower, the flagellum or motile fiber becomes sluggish in its movement and falls off. We then have a still, flattened, globule. In a few seconds there appears in it suddenly and vividly a white cross, forming two diameters at right angles. Almost immediately after, another cross appears, so placed in relation to the first that they together constitute eight radii proceeding from a common center. This complete, the whole interior substance of the living atom is in a state of movement, which results in its being broken up into a large number of bodies that glide for some minutes over each other, but retain as a mass the globular shape. This suddenly breaks up and sets free a large number, usually thirty-six, relatively small forms, exactly like the original body, of which they are now independent living parts—the thirty-sixth part, in fact, of the primal organism. But they are intensely active, and as they absorb and digest everywhere, and live in their food, they rapidly reach the normal full-grown size; but no sooner is this done than each of these goes again through the same process, and thus the organism multiplies by this means alone in a ratio that is, when not considered as an element of adaptation to its special work in nature, simply astounding. The human population of the globe is immense; yet one of these organisms started to divide in this way at any given moment would, in three hours, have given origin to a host that would equal it. This, however, is not the most

important method, physiologically considered, by which these minutest of living beings increase. It is a process that is exhausting to the vitality of the organisms, and ultimately ceases. But another method is forever at work. When self-division has proceeded for a given time, varying with the species, but always regular in the same species, a marked change takes place in the final fissions; that is, if we follow a dividing nomad when the first division is effected, we can only study one of the divided organisms, the others being free to depart to different directions, each one dividing again. But it is only possible to keep one under observation, and when it divides again only one of the subdivisions can be studied, and so on. But when we reach the last act of fission a change takes place. It does not proceed to divide again, but it becomes more or less unlike the normal form, according to the species. In the case of the *Monas Dallingeri* it grows larger, and the front part of its oval body becomes sparsely granular. It swims with great rapidity, and goes almost immediately into the midst of a group of the ordinary forms. One of these becomes attached to it, and the two swim together, their flagella moving in concert. But it is soon manifest that the substance of the smaller form is melting into the larger, until, in a short time, the two become as one. But there is no loss of action for about two minutes, when the flagella fall off, and a clear, sub-oval globule, perfectly inactive, falls to the floor of the stage. It remains inactive, undergoing no discoverable change for thirty-six hours, and then it bursts, emitting an incalculable host of minute spores, or generic products, which, under observation, rapidly change. They are, when first seen, semi-opaque, globular points, but they rapidly lose their opacity and elongate, passing through successive stages of growth until the full character of the normal adult is attained, when they begin almost immediately to again pass through the self-division into many.

This is a life cycle typical of the entire group of bacteriæ. It thus becomes apparent that the teeming hosts of these putrefactive organisms, as a group, containing the minutest forms accessible to us in nature, have no more caprice in their vital activities than there is in the vermes or insecta.

Their life cycles are as definable as those of a crustacean or a bird. No vital phenomena not to be found amongst higher and larger organisms are observable in this minute field of living things.

The discovery that putrefaction is the result of life and not of death, and that the disgusting phenomena attending the disintegration of dead bodies, whether of plants or animals, is entirely due to the action of microbes, was first made by Theodore Schwann, and it is by no means an uninteresting reflection that if all microbes could be removed and kept away, dead things would never putrefy, but would dry up and remain unchanged year after year until the end of time. The processes of decomposition being stopped, there is no reason to suppose that those of reconstruction would or could go on, and thus there would be an end to the assimilable food for green crops, as well as to that for the myriads of creatures that live upon them.

Within the past year or two some very interesting experiments have been made by the pupils in my laboratory to ascertain the number of germs or microbes contained in the average atmospheric air at midday in populous neighborhoods. In the neighborhood of Fourteenth Street and Sixth Avenue, New York, the results we obtained were as follows:

	Per Cubic Yard.
In January the number of germs of all kinds amounted to . .	3,106
In April the number of germs of all kinds amounted to . . .	4,818
In June the number of germs of all kinds amounted to . . .	5,819
In July the number of germs of all kinds amounted to . . .	5,791
In September the number of germs of all kinds amounted to .	5,900
In November the number of germs of all kinds amounted to .	3,601

I do not give these figures because they have any particular significance in themselves, for the germs were not classified. I merely introduce them because Miquel, of Paris, who has made much more complete and exhaustive experiments, has stated as a fact that the mortality from zymotic and infectious diseases always increases with the number of microbes in the atmosphere. Exactly how his conclusions were formed, I am unable to say; but if he based them on a comparison of mere mortality statistics

covering a certain time, I should be inclined to question the utility of applying them too broadly; because, as a matter of fact, I am not aware that the microbes connected with the common infectious diseases have been discovered in the air, or that they ever exist there outside of the immediate vicinity of the seat of the disease. Miquel has, however, rendered enormous services by his experiments, because they have pointed out how we may avoid the conveyance of microbes into the atmosphere from places where pathogenic forms are known or likely to be present, and have led our sanitary authorities to insist upon vast improvements in the construction and arrangement of hospital wards and of sick-rooms. They have also directed the attention of brewers and distillers and dairymen to the importance of shunning all circumstances tending to disturb and distribute dust in the neighborhood of their factories, and what is still more important, have formed the foundations for the very common use by everybody of antiseptics and disinfectants.

The microbes of the soil are far more numerous and interesting than those of the air; because while some play a most important part in all the processes of putrefaction and nitrification, and are positively indispensable to us, others are not only detrimental to the growth of vegetation, but become breeders of many of our common diseases.

In the experiments performed by my pupils to ascertain the number of microbes present in the soil, I made them adopt the method of triturating a weighed quantity of the dried sample with a measured quantity of sterilized water. Of the fluid thus prepared, 1 cubic centimeter was taken by means of a sterilized pipette, and transferred to a flask containing sterilized bouillon. In this way they found, during the summer, the following results, expressed in numbers of microbes per gram of soil:

Soil from upturned street, near the Battery, New York	1,565,000
Soil from upturned street, Park Place, New York	2,100,000
Soil from upturned street, Twenty-fifth Street and Tenth Avenue	1,830,000
Soil from upturned street, Ninety-fifth Street and Ninth Avenue, New York	842,000

As in the former experiments with the air, we did not attempt to ascertain the characteristics of each type of microbe in these soils, because to have made such an attempt would have entailed more time and labor than I could afford for successive cultivations and transplantations into various media at various temperatures, and would have necessitated the inoculation of various animals which were not at my disposal. It is, therefore, only fair to say that my figures do not necessarily imply the presence of pathogenic forms. Samples of soil may owe vast variations in the number and species of microbes they contain to minor local influences, and most of the microbes are located very near to the surface. While it is an undoubted fact that the majority of them are harmless when introduced into the human and animal body, it has been shown that the bacilli of tetanus, anthrax, typhoid fever, malaria and cholera may easily exist among them, and this gives emphasis to the point that the constant upturning of streets is detrimental to the health of the community, and that some efficient arrangement is called for whereby the upturned soil may be prevented from becoming dry and transformed into dust. Wherever we have the dust we have the microbes, and there is no form in which they are better conveyed or more readily propagated.

In accordance with the workings of a very familiar natural law, the dust-borne soil microbes are particularly dangerous in the summer-time. I refer to the law under which every process of vegetation is hastened or retarded by conditions dependent on the temperature and the moisture of the surrounding medium. It finds its limit within certain extreme degrees of temperature, and its greatest activity at a fixed mean between these extremes. The cardinal points of temperatures, as they affect the life of cells, are, therefore, distinguished as minimum, maximum and optimum. If the raising or lowering of the temperature beyond the maximum or minimum point reaches certain extreme degrees, animation is suspended or life is destroyed.

The variations that occur in all these respects are in conformity with the species, the state of development and the character of the environment.

From the experiments I have made, and from the data collected from various investigators, the non-parasitic species, if well and properly nourished, have a tolerably wide range and a high optimum of growth temperature. For the *Bacillus subtilis*, for example, it is between 42° and 122° F., the optimum being at about 86° F. For *Bacterium termo* it is between 42° and 105° F., the optimum being 85° to 95° F. For *Bacillus amylobacter* it is about 105° F., the maximum being, say, 114° F. The optimum temperature for the formation of spores in endosporous bacilli appears to approach that of growth.

The temperature of vegetation may, in the case of the majority of bacteriæ, be so lowered without destruction of life, however, that we may practically say there are no limits. I have demonstrated, over and over again, for example, that many forms are unaffected when they are frozen in a fluid at a temperature of 14° F., and afterwards thawed out. The upper death temperature, on the other hand, is the same—or nearly the same—for the majority of vegetative cells, say 125° to 155° F., although the spores of some bacilli are capable of enduring extreme high temperatures—225°, 235°, 250° F.

You will understand that I am briefly giving you examples of general rules, and that these are not affected by the exceptions which may occur in some special cases, depending in part on the species and individuals, and in part on the external conditions, such as length of time during which they are heated, dried or soaked, and the nature of the surrounding fluid.

Miquel describes a species which develops rapidly at a temperature much over 125° F., and another which, while growing and forming spores in a nutrient solution at 165° F., ceases to live when the heat is carried to 167° F. Again, Duclaux, in his studies upon the *Bacillus tyrothrix*, which he obtained from cheese, made some very interesting and important observations upon this point. He found that, cultivated in a neutral fluid, the cells were only killed at a temperature of 195° to 205° F., while the ripe spores remained capable of germination in a similar fluid when subjected to a tem-

perature of 240° F. It is a most important fact that in milk the spores of one of this species remained uninjured when heated to 250° F. The same spores immersed in gelatine were killed directly they reached 230° F.

Of all the conditions connected with the growth and development of germs, the most important is the requisite supply of water. Withdrawal of water, to the point of air-dryness, invariably and surely kills vegetative cells, such as we are accustomed to meet with in every-day life, in a very short space of time. Here again, however, the resistance of spores is greater than that of the vegetative cell; for it has been shown that *Bacillus subtilis* will withstand it for a period of three years, and that other species are still more obdurate. It has been demonstrated that oxygen is not equally necessary to the existence of all species of germs, and there are cases known where oxygen has impeded, and will even destroy, the vegetation of cells when applied under high pressure. *Bacillus anthracis*, for example, has been known to remain alive for a fortnight in oxygen under a pressure of 15 atmospheres, but was found to be dead at the end of a month; and Duclaux has proved that many air-germs, when withdrawn from the other necessary conditions to their growth, will degenerate and die more quickly under the continued effect of atmospheric oxygen than when oxygen is excluded. He gives, as an illustration of this, the fact that some glass bottles, which had been used by Pasteur in 1860, were kept hermetically sealed, and were, in fact, altogether lost sight of. At the end of twenty-five years it was found that, while the contents of the bottles were completely destroyed, the bacteriæ with which they were infested were quite alive and capable of development. Some other bottles of the same age, which had been used for experiments at the same time, had not been sealed, but had merely been plugged with cotton-wool. The plugs had been kept all the intervening years quite free from dust and quite dry, but were in full contact with the air. These did not contain a single living germ. A few similar plugs, which were only five or six years old, however, contained germs still capable of development.

Our knowledge of the most appropriate feeding media for all forms of bacteriæ or mould is very far from complete; but even if we were more advanced in this direction, there are, besides the actual food requirements, other essential chemical qualities which must be possessed by a liquid that is destined to cultivate different species. A very large number of organisms flourish best, all other conditions being the same, in a solution with a neutral or a slightly alkaline reaction. In these cases, if the reaction should become sufficiently acid, the vegetative process is at once hindered or wholly stopped. Thus, the development of *Bacillus subtilis* is impeded if one five-hundredth of sulphuric or tartaric acid or if two-tenths of lactic or butyric acid be present; and since the prejudicial acid compounds are often formed as a direct result of the vegetative process itself, the action of the microbe is very frequently stopped by the accumulation of its own products.

The branch of bacteriology to which I have given the greatest share of my own attention relates more particularly to the industries of fermentation. Its proper application to these industries is of comparatively recent date, and I think it is no exaggeration to say that its present enormous development is primarily due almost entirely to the laborious investigations of two men. The first was the late illustrious Frenchman, Louis Pasteur, and the second is the well-known Dane, Emil C. Hansen, of the Carlsberg laboratory. Until Pasteur published the results of his first experiments in 1857, little or nothing was known of the micro-organisms which we now fully recognize as playing the all-important part in fermentation as well as in many processes in the economy of nature and the arts. It is true that in 1836, Cagniard de la Tour and Schwann simultaneously discovered that, during fermentation, yeast developed new cells by budding or sprouting; but that this conveyed nothing to the minds of their scientific contemporaries is amply shown by the utterances of Liebig in 1839. This great chemist at that time promulgated the theory that when nitrogenous matter is brought into contact with oxygen, it undergoes a change of composition which disturbs

the equilibrium of the attractive forces previously binding the atoms together. This sets up an alteration of arrangement in the constituent atoms of the molecule, which causes a molecular motion to be transmitted not only through all the parts of the nitrogenous matter, but also to the molecules of such fermentable substances as may be in contact with it. The result of this motion in the sugar molecule was, according to Liebig, a rearrangement of its elementary atoms, resulting in the production of alcohol and carbonic acid gas. You will see, of course, that this does not contemplate any physiological action whatever, and will understand the revolution created by Pasteur when he demonstrated that alcoholic fermentation is a chemical action connected with the vegetable life of certain cells, and effectually proved that, providing the air is quite germless, the so-called unstable substances of the albumen type never develop organized bodies, and can never undergo either putrefaction or fermentation.

You are, of course, aware that, prior to the work of Pasteur, the great majority of scientists inclined to the theory of spontaneous generation. As a first step necessary to demolish this belief, it was necessary that all experiments should be conducted with liquids known to be free from all kinds of organized germs. It was soon discovered that this freedom is attained by submitting the liquid to be operated on to a high temperature. Different liquids were found to require different degrees of heat in order to make them sterile. For acid fluids, such as vinegar, for example, a temperature of 122° F.; for hopped wort, 158° F. to 167° F.; for unhopped wort, 194° F.; for milk, about 230° F., and some other organic liquids as high as 248° F. Sour milk requires to be heated 36° F. to 54° F. less than fresh milk, and while a temperature of 212° F. suffices for new wine, that in which the acidity has been neutralized by carbonate of lime requires a much higher degree of heat.

In order to avoid all possibility of error from this source, Pasteur boiled all the liquids he worked with, in a flask known as the Chamberland flask, with a long drawn-out neck brought to a fine point at the top. By this simple

precaution he not only secured the boiled liquid against the invasion of outside germs, but ensured the proper oxidation of the dissolved substances contained in it. The theory that oxidation of albuminous matter develops cells of yeast or other ferment was readily and finally disposed of by these means, and Pasteur soon declared that under no known circumstances can albuminous matter be transformed into yeast or any other organized ferment.

This theory being abolished, the next to be dealt with was that of the school which held that one kind of ferment was capable of developing into other varieties. This necessitated a special series of experiments, which were carried out by Pasteur with great skill and care. He avoided all the errors of his predecessors and contemporaries by operating on pure specimens of individual moulds and ferments. These he cultivated under the most varied conditions without ever succeeding in finding any evidence of the alleged transformation. As he says himself, "during the weeks and months over which my observations extended, there was not the least formation of yeast from *Penicillium glaucum*, and although I have frequently repeated this and other experiments of a similar kind, I have never detected the appearance of either ordinary yeast or any true alcoholic ferment when proper precautions were taken to secure a pure growth of the species experimented with." By the same rule "yeast cannot transform itself into any kind of bacteriæ. The cells may, and do, by certain changes in the medium, the temperature and other conditions, change their aspect and become oval, elongated, spherical and larger or smaller in size, but if the yeast be actually pure when sown in the medium, it will never produce the most minute quantity of bacteriæ or of lactic ferment or of lactic acid."

In the course of his preliminary pure culture experiments, Pasteur used flasks with two openings, which have since borne his name, and which differ somewhat from that to which I alluded a moment ago. In the most modern form the extremity of the one opening is fitted with a short piece of india rubber tubing, with its end closed by a glass stopper,

and the extremity of the other is long-drawn-out, and in the shape of a V. Access is gained to the contents of the flask by means of the short tube, either to impregnate the liquid with the ferment to be cultivated, or to remove a small portion of that which has been there produced. The finely-drawn-out end of the long tube is lightly plugged with asbestos or cotton wool. You will see that Pasteur was able not only to sterilize his liquids in these flasks, but to maintain them in a sterilized condition while allowing free access for the necessary air. The nutritive fluid which he selected as most propitious for each variety of germ was first boiled in the flask, and, after cooling, was impregnated by touching it with the end of a piece of platinum wire, bearing a very small quantity of the purest obtainable specimen of the particular ferment. The germs from the air were all rigorously excluded, and the liquid itself was sterile. It follows from this that even if the ferment introduced contained more than one kind of organisms, the predominating species or race would be in exactly the most suitable conditions for rapid development, and would crowd out the weaker or minority species. Hence, in a second growth, started from the product of the first, the impurities which may have existed with the original specimen would naturally be fewer and would finally completely disappear, leaving only the one selected race in mastery of the field.

It would be obviously impossible, even if it were not unnecessary for me to dwell at any length upon the enormous extent and variety of Pasteur's experiments, but I think it will be proper to briefly summarize the main conclusions that he drew from them in the following way:

(1) Alcoholic fermentation is a chemical action connected with the vegetable life of cells, which cells, in the absence of free oxygen, live by withdrawing the oxygen they require from certain carbohydrates, such, for example, as sugar.

(2) Only one definite class of cellular organisms are capable of decomposing sugar into alcohol and carbonic acid, and all the members of this class more or less resemble each other.

Thus you will perceive that Pasteur divided all living

germs into two classes: (1) *Ærobian*, or those which cannot live without air; and (2) *Anærobian*, or those which for a time can do without it, and he placed the alcoholic ferments in the latter class.

At this late day and in the light of all our present advantages, it is difficult for us to realize that the proofs adduced by Pasteur in support of his life theory failed to convince Liebig. That they did so fail is, however, shown by the fact that in 1869 Liebig wrote: "I had admitted that the resolutions of fermentable matter into compounds of a simpler kind must be traced to some process of decomposition taking place in the ferment, and that the action of this same ferment on the fermentable matter must continue or cease according to the prolongation or cessation of the alteration produced in the ferment. The molecular change in the sugar would, consequently, be brought about by the destruction or modification of one or more of the component parts of the ferment, and could only take place through the contact of the two substances. The idea that the decomposition of sugar during fermentation is due to the development of the cellules of the ferment is, however, in contradiction with the fact that the ferment is able to bring about the fermentation of a pure solution of sugar. Now, since the greater part of the ferment is composed of a substance that is rich in nitrogen, sulphur and phosphates, how is it possible to admit that the number of yeast cells can increase in a pure solution of sugar devoid of these elements?"

At the first blush this does not sound unreasonable; but the argument was based on a fallacy, and the way in which Pasteur met it was eminently characteristic of his practical mind. He made fresh experiments, starting with weighed quantities of ferment, and noting the weights of yeast developed by growth in pure sugar water. To prove the intimate connection between the development of ferment cells and the decomposition of sugar, he demonstrated the budding of the cells under the microscope, and showed that while *fermentation* was checked by chloroform, prussic acid, bichloride of mercury, ether, creosote, and the oils of tur-

pentine, lemon, cloves and mustard, *hydrolysis*, by the soluble albuminous bodies known as *Enzymes*, was not interfered with by any of these substances. He also showed that while yeast could not permanently reproduce itself in solutions of pure sugar only, it nevertheless carries with it enough nitrogenous and mineral matter for the immediate needs of its own life, besides providing for considerable development of new cells. He showed this in a very ingenious way by adding to a sugar solution the filtered extract from 5 grams of dead yeast, and by impregnating the mixture with only an infinitesimally small quantity of living and healthy yeast. As the result of this experiment, he found that 10 grams of the sugar contained in the solution were decomposed in nine days; whereas, in a similar sugar solution, to which he added the much larger quantity of 5 grams, by weight, of healthy yeast, 12·9 grams of sugar were decomposed in six days. He also prepared a sugar solution containing only the *ashes* of yeast and a salt of ammonia, and was able to prove beyond doubt that the yeast could live in it and increase in weight. Since this solution contained no trace of albumen, how could the argument that "a ferment consists of an albuminous substance undergoing decomposition" do otherwise than fall to the ground, never to arise? Whether Liebig was really convinced of his errors we shall never know, for he was too obstinate to publicly admit his defeat.

He contented himself, however, by owning that "from a chemical point of view, a *vital* action is a phenomenon of motion, and that, in this double sense of life, Pasteur's theory agreed with his own and was not in contradiction with it." He said: "The only co-relation between the physiological act and the phenomenon of fermentation is the production, in the living cell, of a substance which, by some special property (analogous to the action of diastase), may bring about the decomposition of sugar in other organic molecules. The physiological act in this view would be necessary for the production of this substance, but would have nothing else to do with the fermentation."

[*To be concluded.*]

NIAGARA ON TAP.*

By T. Commerford Martin.

It is a singular fact that no great work in art or literature is associated with Niagara, and that almost, if not quite, alone among the natural glories of this western world, its name does not call up at once some famous, immortal painting or poem, some distinctive piece of description or fiction. I do not say that Niagara is without minor tributes in art or song; but that no transcendent sustained effort of the intellect has hitherto been called forth by it. Our mountains, our plains, our seashore, our continental rivers, even our lonely New England farms and our isolated Louisiana bayous, have their artists of one sort or another, and have even created schools; but Niagara's emerald front is as bare of memorable inscription as that of an Alaskan sea-wall glacier, and her wreathing pillars of mist are never seen touched with the rainbow splendor of any enduring imagery of genius. Yet it cannot be said that the immensity of the subject has dwarfed or dulled the observer. Even the deluge once found a spirited reporter; and the newly-married couples who swarm hither at all seasons are not dismayed by its grandeur, but hear in its solemn music only a cheerful echo of the recent wedding march, to which they so blithely took a Niagara plunge into the realities of life. As a matter of fact, there have been notabilities not a few who found Niagara smaller and meaner than their dreams had depicted; some have even confessed aloud their bitter disappointment at its ridiculous inadequacy. For example, Mrs. Jamieson, a well-known English writer in her day, was sorry to have seen the Falls, preferring her imagination of them; while not long since Colonel Ingersoll objected eloquently to their crude display of mere barbaric and dangerous power. Such criticisms are offset by elo-

*A lecture delivered before the Franklin Institute, January 3, 1896.

quent utterances from Hawthorne, or Moore, or Dickens, or Margaret Fuller, that serve to eke out the scant measure of one's own vocabulary of delight and wonder; but the fact remains that Niagara is to this day well-nigh unhistoried and unsung—except in the excursion literature of the New York Central Railroad Company.

Such being the case, it will not, perhaps, seem wildly fanciful if I venture to think that hereafter the great work of genius that is to associate itself in the world's thought with Niagara is to be a piece of engineering. The mere idea will be violently reprehended by romanticists and those lovers of natural beauty who forget that their own intrusion into primeval solitudes is but part and parcel of the vulgarizing familiarity they affect to despise. For my own part, I have never been able to determine the point at which natural scenery should remain inviolable by man. It is an obvious fact that the grandeur of the setting is always more or less a pledge of the harmonization with it of the work that is to be brought into it by the ingenuity and intrepidity of the engineer. The Atlantic surely does not lose anything by contrast with the swift and stately steamer that shuttles through its storms and calms. The railroads that scale the Andes add new elements of the colossal and grandiose to the scene, as do the St. Gothard and Simplon tunnels to the overpowering magnitude of the Alps they pierce. So, too, I wish to assert that the utilization of Niagara by electricity is in no sense a belittling of its splendors or a cheapening of its charms. One is still able, without a single disturbing hint of the existence of the enterprise, to see the wild cataract leap in glory; one still awaits the coming and going of the land-locked rainbows; one may still behold white clouds born out of the sonorous conflict of rock and foam, and watch them float softly away; one still holds the breath instinctively as the ocean torrent plunges madly along the gorge; and one will still pause for many a lazy hour in the hollow of the hills where the tired waters circle slowly and slowly in malachite coils and languid ripples. Yes, we revel as of wont in all the old and unworn beauties of the scene: but we shall enjoy, and many

with us, through the years to come, a new pleasure from the engineering spectacle in which, with consummate foresight of aim, dignity of purpose and skilful adaptation of means to end, Niagara has been taught to do good as well as to be natively awful and beautiful. So far from apologizing for the presence of modern mechanism and engineering triumphs in this realm of natural masterpiece, I would urge that we have here a promise and augury of the part that electricity is to play in the larger reclamation of hitherto wasted forces of nature—a process of utilization that will give us light, heat, power and locomotion over wide areas without grime or dust, and without a smudge in the sky, so that manufacturing cities, far larger than New York, will know an air as pure and sweet and serene as though not a wheel were turning anywhere.

The broad idea of the utilization of Niagara is by no means new; for even as early as 1725, while the thick woods of pine and oak were still haunted by the stealthy redskin, a miniature saw-mill was set up amid the roaring waters, that long remained far more familiar with the savage war-cry of Iroquois or Senecas than the creak and splash of our ancestors' primitive machinery. The first systematic effort to harness Niagara was not made until nearly 150 years later, when the present hydraulic canal was dug and the mills were set up, which, like hucksters' booths around an old Italian Cathedral, disfigure the banks just below the stately Falls, their discharge of the water uneconomically used at low pressure being the only picturesque element in the scene.

It was long obvious that even an enormous extension of this surface canal system would not answer for the proper utilization of the illimitable energy contained in a vast stream of such lofty fall as that of Niagara. Let us recall what Niagara is. It is the point at which are discharged, through two narrowing precipitous channels, only 3,800 feet wide, the contents of 6,000 cubic miles of water, with a reservoir area of 90,000 square miles, draining 300,000 square miles of territory. The ordinary overspill of this Atlantic set on edge has been determined to be

equal to about 275,000 cubic feet per second, and the quantity passing is estimated as high as 100,000,000 tons of water per hour.

The drifting of a ship over the Horseshoe Fall has proved it to have a thickness at the center of the crescent of over 16 feet. Between Lake Erie and Lake Ontario there is a total difference of level of 300 feet, and the amount of power represented by the water falling within that distance has been estimated on different bases from 6,750,000 horse-power up to not less than 16,800,000 horse-power, the latter being a rough calculation of Sir William Siemens, who, in 1877, was the first to suggest the use of electricity as the modern and feasible agent of converting into useful power some of this majestic but squandered energy.

It was Mr. Thomas Evershed, a civil engineer of appropriate name, who unfolded the plan of diverting part of the stream at a considerable distance above the Falls, so that no natural beauty would be interfered with, while an enormous amount of power would be obtained with a very slight reduction in the volume of the stream at the crest of the Falls. Essentially scientific and correct as the plan now shows itself to be, it found prompt criticism and condemnation, but not less quickly did it rally the able and influential support of Messrs. W. B. Rankine, Francis Lynde Stetson, Edward A. Wickes and Edward D. Adams, who organized the corporate interests that, with an expenditure of $5,000,000 in five years, have carried out the noble work which it affords me pleasure to bring to your notice this evening. The evolution of the plans and the execution of the work constitute a great many separate chapters of history, but we shall only be able to find time for the salient features and the concrete results.

So many engineering problems arose early in the enterprise, that, after the survey of the property in 1890, an International Niagara Commission was established in London, with power to investigate the best existing methods of power development and transmission, and to select from among them, as well as to award prizes of an aggregate

$22,000. This body included men like Lord Kelvin, Mascart, Coleman Sellers, Turrettini and Prof. Unwin, and its work was of the utmost value. Besides this, the Niagara Power Company and the allied Cataract Construction Company enjoyed the direct aid of other experts in a consultative capacity, while it was a necessary consequence that the manufacturers of the apparatus to be used threw upon their work the highest inventive and constructive talent that they could possibly employ. It was a not less necessary consequence that there should be and will be controversy as to the origin of this or that conception incorporated in the details adopted, and an equally earnest disclaimer as to the things discarded. I suppose this must always be so. One comes, indeed, to question the importance or validity of any new idea or achievement that has not a dozen claimants and a score of infringers.

The final plan adopted will now be referred to, although I may first contrast it with an amusing one in which the promoter intended to use what I may call outdoor wheel pits, or funnels stuck up immediately under the flow of the water, debris, rocks and rolling tree trunks of the Falls. This ingenious plan was seriously entered for the prize of $100,000 offered by Buffalo for the best plan of utilizing Niagara, but you will agree with me that the perfected and concentrated Evershed scheme is the better of the two. It comprises a short surface canal, 250 feet wide at its mouth, 1¼ miles above the Falls, far beyond the outlying Three Sisters Islands, with an intake inclined obliquely to the Niagara River. This canal extends inwardly 1,700 feet, and has an average depth of some 12 feet, thus holding water adequate to the development of about 100,000 horse-power. The mouth of the canal is 600 feet from the shore line proper, and considerable preliminary work was necessary in its protection and excavation. The bed is now of clay and the side walls are of solid masonry, 17 feet high, 8 feet at the base and 3 feet at the top. The northeastern side of the canal is occupied by a power-house and is pierced by ten inlets, guarded by sentinel gates, each being the separate entrance to a wheel pit in the power-house, where the water is used

and the power is secured. The water, as fast as used, is carried off by a tunnel to the Niagara River again.

Just here I may point out one of the material differences in the general Evershed Niagara plan made by the adoption of electricity. At first it had been deemed natural to plant individual factories widely apart along such a canal, each developing its own power for itself and using a tunnel as a common raceway recipient for the water used. But with

electricity it at once became easier and better to develop and generate all the power wholesale in one spot and then distribute it electrically to the various factories needing it. This released the factories from a narrow choice of sites, gave freedom of location for various industries, concentrated the work of power generation, lessened the expense and enabled each mill-owner to take just the power that he needed at the moment and no more. We detect here one of the greatest virtues of electrical transmission of power.

The old-fashioned water-mill or factory has had to get right down in the hot, dark valley, and gather there, under insanitary conditions, its human forces. The new electric factory lifts itself to the heights and in free air and sunshine, in defiance of all ancient saws and proverbs to the contrary notwithstanding, grinds away cheerfully with the water that may have rushed by its door half an hour ago.

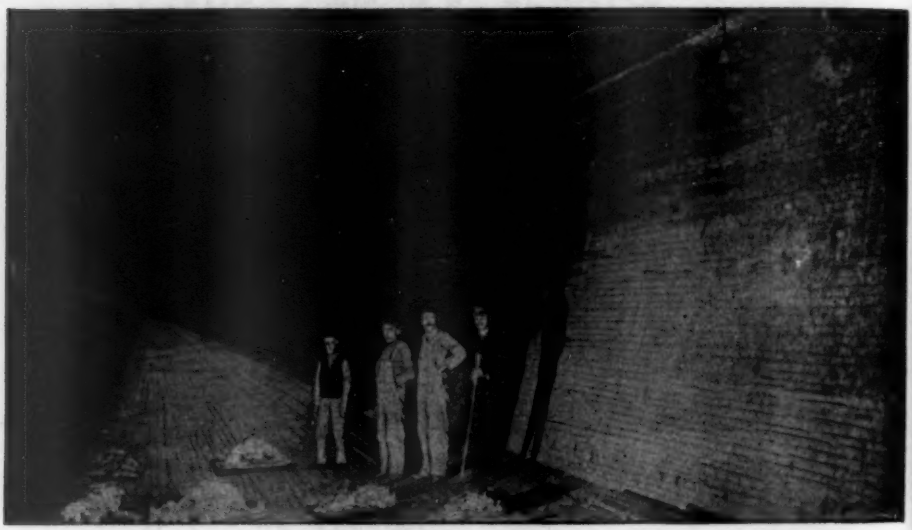
The massive canal power-house, of whose machinery we shall have more to say in detail further on, is a handsome building, designed by Stanford White, and likely to stand at least until Niagara, spendthrift fashion, has consumed its way backward through its own crumbling strata of shale

View of power-house from canal.

and limestone to the base of it. This building is outwardly of hard limestone and inwardly of enamel brick and ordinary brick coated with white enamel paint. It is 200 feet in length at present, and has a 50-ton Sellers electric traveling crane for the placing of machinery and the handling of any parts that need repair.* The wheel-pit, over which the power-house is situated, is, in reality, a long, deep, cavernous slot, at one side under the floor, cut in the rock, parallel with the canal outside. Here the water gets a fall of about 140 feet before it smites the turbines; and after delivering up its energy

*Since this lecture was delivered, the extension of the power-house has been begun, being rendered necessary by the contract for current in Buffalo.

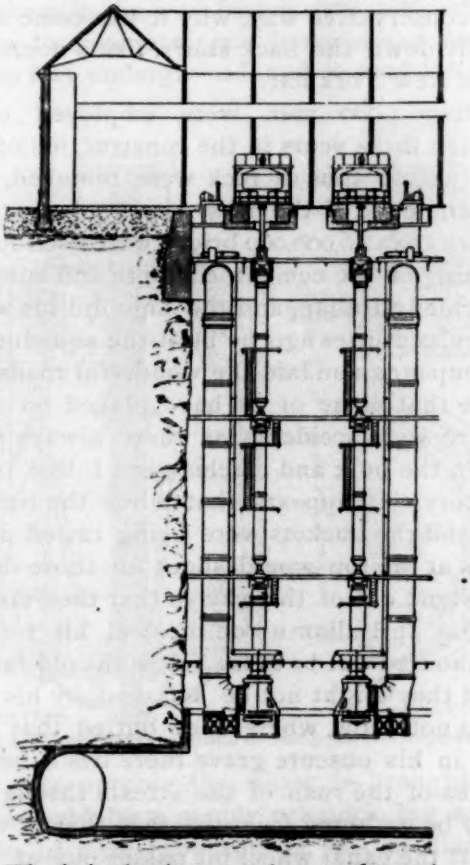
generously to these, like Santa Claus coming down the chimney with Christmas gifts, it runs off and disappears into the tunnel raceway. The arrangement of the dynamos generating the current up in the power-house is such that each of them may be regarded as the screw at the end of a long shaft, just as we might see it if we stood an ocean steamer on its nose with its heel in the air. At the lower end of the dynamo shaft is the turbine in the wheel-pit bottom, just as in the case of the steamer shaft we find attached to it the big triple or quadruple expansion marine



View in the great tunnel.

steam-engine. Perhaps we might compare the dynamo and the turbine to two reels stuck one at each end of a long lead-pencil, so that when the lower reel is turned the upper reel must turn also. You might also compare the dynamos to bells up in the old church steeple, and the turbines to the ringers in the porch playing the chimes and triple bob majors by their work on the long ropes that hang down. The turbines in the Niagara power-house receive their water-supply from the canal through the huge penstocks or intake pipes; but after the water has done its lofty tumbling act of

140 feet and passed through the turbines, it has to get away, and this is the reason for the huge waste-water tunnel or tail raceway. The wheel-pit which contains the turbines is 178 feet in depth, and connects by a lateral tunnel with the tunnel running practically at right angles.



Wheel-pit, showing power-house and tunnel.

This main tunnel is no less than 7,000 feet in length, with an average hydraulic slope of 6 feet in 1,000. It has a maximum height of 21 feet and a width of 18 feet 10 inches, its net section being 386 square feet. It is as capacious as any of the Paris sewers that Victor Hugo

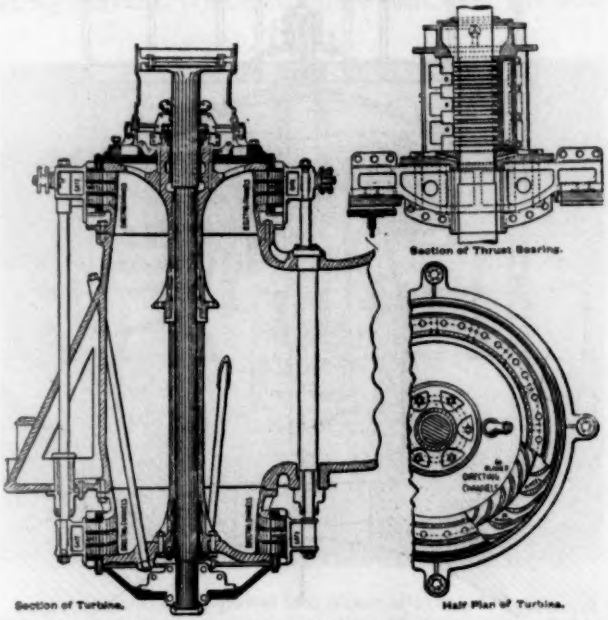
wrote about. The water rushes through it and out of its mouth of stone and iron at a velocity of 26½ feet per second, or nearly 20 miles an hour. Evidently there is quite a little energy left in the stream when it emerges at the Suspension Bridge and hastens to explain in a subdued way to the other main stream that has shot the chute in the old conservative way, why it has come more quietly and usefully down the back stairs, like a domestic in some fashionable New York flat.

More than 1,000 men were employed continuously for more than three years in the construction of the tunnel. More than 300,000 tons of rock were removed, which have gone to form part of the new foreshore near the power-house. More than 16,000,000 bricks were used for the lining, to say nothing of the cement, concrete and cut stone. The labor was chiefly Italian, and the dago did his work just as well as when, centuries ago, he built the aqueduct across the Roman Campagna and laid the wonderful roads in England and Europe that some of us have played on as boys. Of course, there were accidents, as there always will be with humanity in the bulk and careless, but I like to recall one pathetic story. It appears that when the rock was being excavated and the buckets were being raised and lowered, the Italians at the top would shout to those below underground to stand out of the way so that they might not get hit. One day an Italian up on top lost his footing, but as he fell he shouted out to those below the old familiar warning, so that they might not be smashed by his descending body. I do not know where they buried that dago, but I know that in his obscure grave there lies a hero.

Some idea of the rush of the stream through that dark tunnel may be gathered from the fact that a wooden chip thrown in at the canal wheel-pit passes out at the Suspension Bridge portal in 3½ minutes, which is five times as fast as you or I can walk. The brick that fences in that headlong torrent consists of four rings of the best hand-burned brick, of special shape, making a solid brick wall 16 inches thick. In some places it is thicker than that. Into this tunnel discharges also, by a special sub-tunnel, the used-up

water from the water-wheels of the Niagara Falls Paper Company.

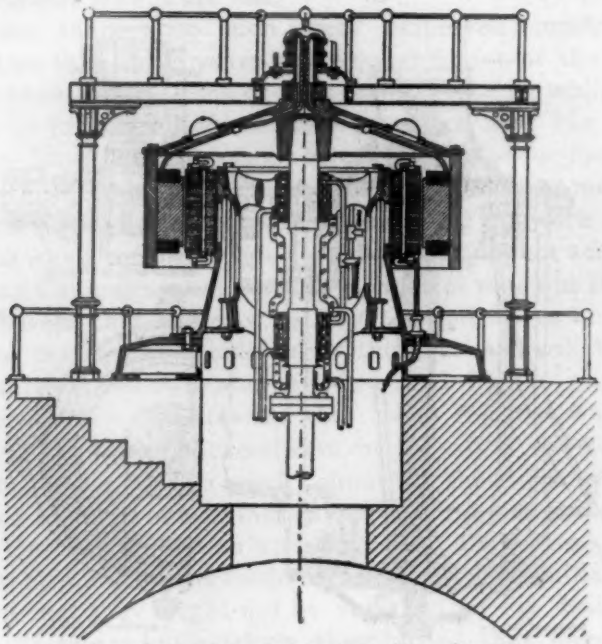
We must come back again to the stately power-house, on the bank of the intake canal, and see what kind of machinery it has been filled with; but before studying the dynamos it will be natural and proper to glance at the turbines that drive them in the way I have just alluded to. These wheels have to generate 5,000 horse-power each, at a distance of 140 feet underground, and to send it up to the sur-



Vertical and horizontal sections of the 5,000 horse-power turbines.

face. For this purpose the water is brought down, as I have already said, by a supply penstock, big as a bowling-alley, made of steel tube and 7½ feet in diameter. This water strikes what is essentially a twin wheel, each receiving part of the stream as it rushes in, the arrangement being such that each wheel is three stories high, the water under the upper half serving as a cushion to sustain the weight of the entire revolving mechanism. These wheels will discharge 430 cubic feet per second, and they make 250

revolutions per minute. At only 75 per cent. efficiency they give 5,000 horse-power. The shaft that runs up from each one to the dynamo is of peculiar and interesting construction. It is composed of steel, $\frac{3}{4}$ of an inch thick, rolled into tubes which are 38 inches in diameter. At several intervals, as you see, this tube passes through journal bearings or guides that steady it, at which the shaft is narrowed to 11 inches in diameter and solid, flaring out again



Section of 5,000 horse-power two-phase alternator.

each side of the journal bearings. The speed gates of the turbine wheels are plain circular rims, which throttle the discharge on the outside of the wheels, and which, with the co-operation of the governors, keep the speed constant within 2 per cent. under ordinary conditions of running. These wheels are of the Swiss design of Faesch & Picard, and have been built by I. P. Morris & Co., of Philadelphia, for this work.

The big dynamos must now receive our attention. They

are of the Tesla two-phase type, the principle embodied in them being a radical departure in dynamo electric machinery, and one of the many striking innovations and improvements that electricity owes to Mr. Nikola Tesla. At first, when electricity was proposed as the means of transmiting this energy, the direct continuous current was advocated, and even insisted on, by men so world-famous as Lord Kelvin. But it was found that the continuous form of current, useful as it is, would not answer, and then choice settled upon the alternating current, which could be sent over the fine wires

5,000 horse-power two-phase alternator.

at a high voltage or potential, and be reduced in pressure or otherwise converted at the various points of utilization. But even the alternating current in its simple form is not all that is needed, and hence, after everything had been carefully estimated, weighed and discussed, Mr. Tesla's idea as to the superiority of a two-phase current was adopted, and the apparatus was built on that plan by the Westinghouse Company, as the best to meet all the exacting requirements of the great enterprise. In popular language, it might be said that each of these dynamos, not

unlike the turbines, consists of two working interlocked together. In technical language it may be stated that each of these dynamos produces two alternating currents, differing 90° in phase from each other, each current being of 775 ampères and 2,250 volts, and the two currents added together making in round figures very nearly 5,000 horse-power. This amount of energy in electrical current is delivered to the circuits for use when the dynamo is run by the turbine at the moderate speed of 250 revolutions per minute, or say four revolutions a second. Here then we have broadly a Tesla two-phase generator, but of course it embodies the novel suggestions and useful ideas of many able men, among whom should be specially mentioned Mr. L. B. Stillwell, the gifted young engineer of the Westinghouse Company, upon whom vast responsibility has been thrown, and Prof. George Forbes, of England.

Each generator from the bottom of the bed-plate to the floor of the bridge above it is 11 feet 6 inches high, and the whole machine could be stood inside a room only 15 feet high and 15 feet square. One is really disappointed at seeing it, for you expect your money's worth in a machine that is to deliver 5,000 horse-power of electrical energy, and which receives only 5,150 mechanical horse-power in order to be able to do so. Each generator weighs 170,000 pounds, or 85 tons, and the revolving part alone weighs 79,000 pounds, or nearly 40 tons. In most dynamos, the armature is the revolving part, but in this case it is the field that revolves, while the armature stands still. It reminds you of the figure in dancing where the ladies stand in the centre and the gentlemen circle graciously around them. The revolving field is for all the world like a huge Chinese Mandarin's umbrella, the turbine and shaft being the clubbed handle and stem while the driver or span-piece at the top is the frame, and the field magnet jacketing all around is the silk covering with its fringe. It is noteworthy that if the armature inside the field were to revolve in the usual manner instead of the field, its magnetic pull would be added to the centrifugal force in acting to disrupt the revolving mass, but as it is, the magnetic attraction toward

the armature now acts against the centrifugal force exerted on the field and thus reduces the strains in the huge ring of spinning metal. The stationary armature inside this field is built up of thin sheets of mild steel, laid one on top of the other, as though they were a Brobdignagian pile of buckwheat cakes. Along the edges of these sheets are 187 rectangular notches or juvenile tooth-marks in the cakes, to receive the armature winding in which the current is generated as the field coils fly by. This winding is in reality not a winding, as it consists of solid copper bars $1\frac{1}{32}$ by $\frac{7}{16}$ inch and there are two of these bars in every square hole, packed in with mica as a heat-resisting insulation. These copper conductors are bolted and soldered to V-shaped copper connectors, and are then grouped so as to form two separate, independent circuits. A pair of stout insulated cables connect each circuit with the power-house switchboard.

The rotating field magnet, or umbrella shade fringe, outside this armature, consists of a huge forged steel ring, made from a solid ingot of fluid compressed steel, 54 inches in diameter, which was brought to a forging heat and then expanded on a mandril, under a 14,000-ton hydraulic press, to the ring 11 feet $7\frac{1}{8}$ inches in diameter. On the inside of this ring are bolted twelve inwardly projecting pole pieces of mild open-hearth steel, and the winding around each of these consists of rectangular copper bars encased in two brass boxes. Each pole piece with its bobbin weighs about $1\frac{1}{4}$ tons, and the speed of this mass of steel, copper and brass is 9,300 feet, or $1\frac{3}{4}$ miles per minute, when the apparatus is running at its normal 250 revolutions. Not until the ring was speeded up to 800 revolutions, or 6 miles per minute, would it fly asunder under the impulse of centrifugal force. As a matter of fact, 400 revolutions is the highest speed that can be attained, so that it is hardly likely that the attendants in this power-house will ever have to dodge stray chunks of broken flywheel as do those sometimes who work in big steam plants, although, as will be seen, the revolving field is nothing more than a big flywheel running in a horizontal instead of a vertical plane.

Let us see how this revolving field magnet is connected with the shaft that has to turn it. It is supported from above by a six-armed cast-steel spider, keyed to the shaft, this spider or driver forming a roof or penthouse over the whole machine. The shaft itself is held in two bearings inside the castings, around which the armature is built up. This shaft, at the bearings, is nearly 13 inches in diameter. At the lower end is a flange, fitting with the flange at the top of the turbine shaft, and at the upper end is a taper over which the driver fits. The driver and shaft have a deep keyway, and into this a long and massive key fits, holding them solidly together. The driver is of mild cast steel, having a tensile strength of 74,700 pounds per square inch. The bushings of the bearings are of bronze, with zigzag grooves, in which oil under pressure is in constant circulation. Grooves are also cut in the hub of each spider to permit the circulation of water to cool the bearings, this water coming direct from the city mains at a pressure of 60 pounds to the square inch. The oil returns to a reservoir and is used over and over again.

It will have been noticed that there is plenty of provision against undue heating and plenty of chance for air to circulate. This is necessary, as about 100 horse-power of current is going into heat, due to the magnetization of the iron and the resistance in the conductors themselves. But I may draw your attention to the ventilators or gills in the driver, which are so arranged as to draw up air from the base of the machine and eject it at considerable velocity, so that whatever heat is unavoidably engendered is rapidly dissipated.

[*To be concluded.*]

ELECTRICAL SECTION.

Stated Meeting, September 22, 1896.

MR. CLAYTON W. PIKE, President, in the chair.

A NEW SYSTEM OF SERIES ARC LIGHTING.

BY THOMAS SPENCER.

Any one who has watched the development of arc lighting within recent years cannot have failed to notice the gradual, but radical, changes that have taken place in the methods of delivering light from a central station. Originally the idea seems to have been to break up the source of current supply into a great number of small units. Whether, from an engineering standpoint, this idea was a well-worked-out scheme, or simply the outgrowth of circumstances, is, I think, very easy to answer; for it is usual to begin on as small a scale as possible, so that, in case of failure, the financial loss will be as small as possible. These first attempts proving successful, the conservative feeling, which to a great extent accompanies the investment of money, caused a continuance in the course which had been found practical.

Perhaps in no branch of the electrical industry is this so apparent as in that of arc lighting. However, at present there seems to be a general tendency towards a more economical system, as is attested by the number of large arc light dynamos that are now replacing the numerous small machines; further, by the rapid rise of arc lighting from constant potential D. C. circuits, and also by the general interest manifested in alternating arc lighting. The last named, which, of course, signifies the use of constant potential, is the direction towards which everything seems to be tending, and will be the system most generally employed in the future, unless some efficient method of directly converting heat into electricity is discovered.

There is no question but that a station equipped with large units and supplying one kind of current—and that a

current which can most easily be controlled—is the most efficient. Such is the alternating current. As far as the alternating arc lamp is concerned, it has some points which make it slightly inferior to the direct-current lamp; but experience has shown that these objections are not so serious as at first appeared.

Recently, attempts have been made to use a device by means of which the current is commutated into a fluctuating current, having always one direction, but not with conspicuous success. There are several such plants in England, I believe, and, from some of the criticisms, I should judge that the system is by no means as efficient as it should be to be generally introduced, especially in this country, where, I am sorry to say, a piece of apparatus is apt to fall into the hands of men who fail to give it even the most necessary care. As for the advantages gained by the use of such a device, there is no doubt but that the efficiency of the arc is improved. From my experience I should judge that, as the current is a fluctuating one, the arc would still be noisy, although less so than the unrectified alternating current.

As I have said before, the objections to the alternating arc have not proved to be as serious as they at first appeared. There is a growing tendency towards the use of the alternating arc for all kinds of lighting, and this is especially marked in street lighting. The system which, up to the present time, has been in use may be described as follows: Each lamp is burned separately from a 30- or 33-volt transformer (see *Fig. 1*). The amount of wire used in this system is not generally greater, and often less, than that required in the old direct-current series system. This system works very well and has many good features, perhaps the greatest of which are that each lamp is independent of the rest, and that the pressure on the lamp is low. Furthermore, the lamp has only one series spool of coarse wire, and is free from shunt spools and cut-outs.

There are a great many systems of this sort operating in this country, and some, I believe, have been introduced in England. The only objection to this plan is its high

first cost, occasioned by the necessity of a separate transformer with each lamp. To overcome this objection and at the same time be in position to use the same kind of lamp, Mr. William Smith Horry has devised what he calls his "Reactive System" of arc lighting, which I wish to bring before you this evening. Mr. Horry couples his lamps in series directly in the primary circuit, doing away with the separate transformers. Now, any one who has attempted to run arc lamps in series, which regulate only by variations in current (that is, have only a series spool), knows very well that they will not operate. The reason for this is readily apparent. An arc lamp should depend for its regulation on

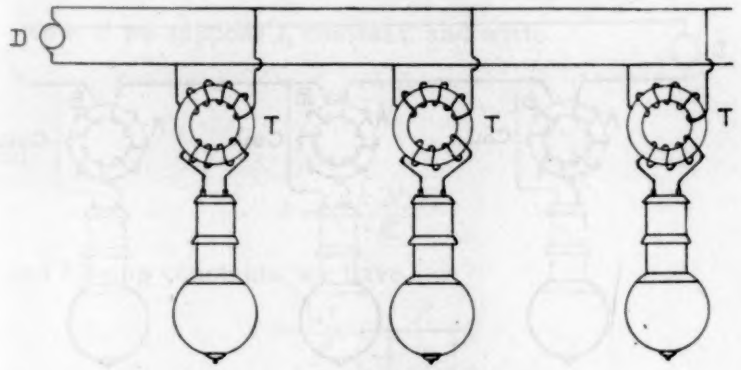


Fig. 1.

something practically affected only by the burning of its own arc. This is evidently not the case with the current where lamps are put in series across a constant potential circuit. In general, when lamps are run in series, we must regulate by the change of E.M.F. around the arc; that is, regulate with a shunt spool. A lamp, of course, similar to the regular series arc lamp, might be used if it were provided with some device to keep the current constant, or a lamp similar to that used on street railway circuits could be devised, but in all of these cases we would have a much more complicated lamp than that used by Mr. Horry.

The principle governing Mr. Horry's system is briefly this:

In shunt with each lamp is placed a small coil of the type known as auto-transformer (*Fig. 2*). The coil *A* is in series with the lamp, and *B* in shunt. With this device the current in the lamp will always be greater than that in the line. Considering the current in the line as constant, which is practically the case where a large number of lamps are in series, we must, as shown above, by some means outside of the lamp itself, cause a change in the current passing through the series spool of the lamp, in order to enable the lamp to feed. This is accomplished by making the amount of iron in the coil small, so that it will soon become saturated and cause the coil to leak, lowering the pressure,

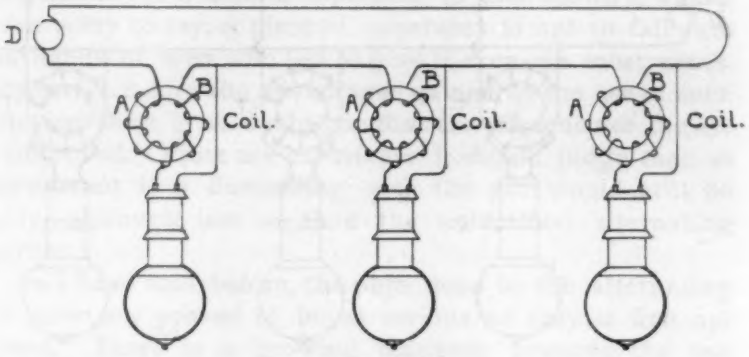


Fig. 2.

which in turn decreases the current and feeds the lamp. This can be more easily understood in the following way: The relation

$$N_1^2 I_1^2 = N_2^2 I_2^2 + \left(\frac{l B}{4 \pi \mu a}\right)^2$$

in a transformer, where there is no leakage between the primary and secondary, is well known. (Fleming, Alternating Current Transformer, Vol. 1, p. 273.) Here N_1 and I_1 are respectively the number of primary turns and the maximum current, and N_2 and I_2 represent the same for the secondary, B the maximum induction, μ the equivalent permeability, l the length of the magnetic circuit, and a its section.

Now the secondary E.M.F. is directly proportional to B, or $B = Ky$, where y is the secondary E.M.F and K a constant. If in the first equation we write x for I_2 and substitute the value of B we have

$$N_1^2 I_1^2 = N_2^2 x^2 + \left(\frac{l K y}{4 \pi \mu a}\right)^2$$

$$\therefore \text{I} = \frac{x^2}{\left(\frac{N_1 I_1}{N_2}\right)^2} + \frac{y^2}{\left[\frac{4 \pi N_1 I_1}{K} \div \frac{l}{\mu a}\right]^2}$$

Now, if we suppose I_1 constant, and write

$$a = \frac{N_1 I_1}{N_2}$$

and

$$b = \frac{4 \pi N_1 I_1}{K}$$

a and b being constants, we have

$$\text{I} = \frac{x^2}{a^2} + \frac{y^2}{\left[\frac{b}{\frac{l}{\mu a}}\right]^2}$$

This is easily recognized as the equation of an ellipse. Plotting this (*Fig. 3*), it is plain that, when the current is small, the E.M.F. varies very little with an increase of current; that is, it behaves in this region as a constant potential circuit. Referring again to our last equation, we see that when

$$\frac{l}{\mu s}$$

becomes greater, that is, when the equivalent magnetic resistance becomes greater, the minor axis of the ellipse becomes smaller. This is accomplished, as before stated, by diminishing the amount of iron in the core of the coil, and, as a result, we will have a coil whose characteristic is an ellipse,

as represented by the dotted lines. In this case the maximum E.M.F. will not be so large; but, as the ellipse is nearly flat, there is a large region over which the coil produces practically constant potential.

There are a few other features in this system worthy of mention. The coil is so proportioned that when the carbons are consumed, and the arc in consequence breaks, the whole current is forced through that portion in shunt with the lamp. The choking effect in the coil is about the same as the E.M.F. taken by the lamp when burning; in fact, it is so close to this that 30 per cent. of all the lamps in circuit may

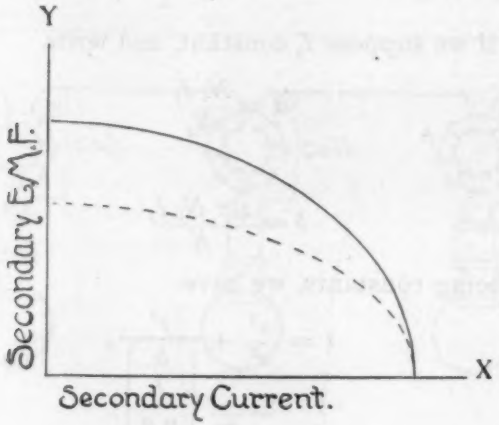


Fig. 3.

be put out without sensibly affecting the ampèremeter in the circuit. The coil then not only acts as a cut out, but also as a regulator.

The advantage which this system shares with that in which lamps are run from separate transformers, is that it is possible to run lamps of widely different candle-power on the same circuit, which is accomplished by changing the coil to conform with the lamp. In this particular, of course, it is an improvement over the ordinary series system, with shunt coil regulation. The number of lamps which it is possible to run in series from a 1,000-volt circuit or trans-

former depends upon the candle-power of the lamps. The coils, as now constructed, will, in this case, take care of twenty-nine 2,000 candle-power lamps. Mr. Horry has also devised a switch-board to be worked in connection with a special transformer in such a way as to give varying primary E.M.F.'s, so that any number of lamps can be run in series within reasonable limits.

As for the practical working of this system, I would say that it is in use in several places in this country. As far as I know, it has been very satisfactory, and there is little doubt that a great future awaits it.

CHEMICAL SECTION.

Stated Meeting, held September 15, 1896.

DR. H. F. KELLER, President, in the Chair.

ON A NEW PROCESS FOR THE MANUFACTURE OF WHITE LEAD.

BY MR. WM. TATHAM,
Member of the Institute.

The process I am about to describe is the joint invention of Wm. P. Tatham, of this city, and myself. Before going into details, I should like to give a very brief *résumé* of what has been done heretofore.

The oldest method of making white lead, commonly termed the Dutch process, is based upon the fact that, if metallic lead be exposed to a heated atmosphere of water vapor, carbonic acid, acetic acid vapor and oxygen, it is converted into a basic lead carbonate. These conditions are obtained, as is well known, by placing pieces of lead, of convenient size, in earthen pots containing a small quantity of acetic acid, and packing these pots in a bed of spent tan or horse manure. The fermentation of the tan, or manure, generates carbonic acid and water vapor, while the heat liberated by the process of fermentation causes the acetic acid to vaporize, and the lead is thereby corroded.

The accepted theory of the process is that the lead is first converted into lead hydrate by the water vapor and oxygen present, and then into a basic acetate by the acetic acid vapor; and, in turn, this latter is driven out by the carbonic acid, and the basic carbonate of lead, or the white lead of commerce, is formed.

There are some objections to this theory; in fact, no one really knows exactly what takes place, but the ultimate result is that basic carbonate is obtained.

One objection to this process is that the quality of the product is somewhat uncertain. An expert, formerly connected with one of the largest and most successful corroding firms of this country, informs me that, after the corroding stacks or beds are put up, the corroder has no power to influence the result; it is largely a matter of temperature and circumstances.

Another objection is the amount of time consumed in corroding the lead. From the time that the lead is put into the beds, about three months must elapse before it is thoroughly corroded. Notwithstanding all this, however, the result in the long run is so successful that the product of the Dutch process is the standard of excellence for white lead; that is to say, if any one should invent a new process, the first thing he would be compelled to do would be to submit his product to a comparison with the product of the Dutch process, and if it were not equal to that, his method would be condemned.

The fact that this process is not perfect is proven by the numerous attempts which have been made to improve it. I think I am not over-stating the facts when I say that the records of the patent office, both in this country and in England, will show that hundreds of new methods have been patented.

These attempted improvements may be divided into two classes:

(1) Those in which metallic lead is corroded.

(2) Those in which the lead is first oxidized into litharge, and then attacked by acetic acid or acetate of lead.

In connection with the first class I may mention the German method, formerly practised in Carinthia, in which sheets of lead were exposed in wooden boxes to the action of corroding vapors. In this country, finely divided lead has been exposed to the action of corroding vapors while being agitated in revolving cylinders. This latter process has given very good results; but it is open to the objection that, in the revolving cylinder, the white lead formed agglomerates into little balls. Any metallic lead enclosed in these balls is protected from the action of the corroding vapors, and, consequently, the white lead formed may contain metallic lead.

The object of all the inventions in this class is to supply as many points of contact as possible between the lead and the corroding vapors. Some of them have been moderately successful.

Where litharge is used, the process is generally one of solution and precipitation—a method invented by Thènard, and commonly known as the Clichy process. This is based upon the fact that, if litharge be digested in a solution of normal acetate of lead, a sub-acetate is formed, which, if exposed to the action of carbonic acid gas, is decomposed. The basic equivalents are thrown down as a carbonate of lead, while the normal acetate remains in solution, and may be used to attack a second portion of litharge.

The objection to this process is that the product lacks the covering property technically known as *body*, which distinguishes the product of the Dutch method. It was formerly considered that this was due to the fact that the precipitated carbonate of lead was crystalline, while the lead corroded by the Dutch process was amorphous. While this may be true, it is also fairly well settled that the covering quality of white lead is largely due to the presence in the carbonate of a certain amount of hydrated oxide of lead; that is to say, the white lead of commerce is a basic carbonate.

A great many modifications of the Clichy process have been invented. They all depend, however, on the same principle, and their differences are simply differences of method of handling—simply differences of detail.

The most successful precipitation method with which I am acquainted is the one patented by Bradley. The Bradley process consists in subjecting a solution of basic acetate of lead, containing about 11 per cent. basic acetate, to the action of carbonic acid at a temperature of about 120° F., by letting the solution flow over shelves in thin sheets, so as to expose as much surface of liquid as possible to the action of the acid. The essential part of the process, however, consists in stopping it when about one-half of the basic lead oxide has been converted into white lead.

Bradley claims, in his patent, that the white lead produced in this manner contains as high as 30 to 37 per cent. of hydrated lead oxide, and is amorphous.

There is nothing new in Bradley's claim of stopping the conversion into white lead when about one-half of the basic lead oxide had been so converted. The same idea was utilized several years ago in Germany.* The novelty of his invention lies in exposing the solution in thin sheets to the action of the acid. This is not essential, as I have obtained the same results by passing a current of carbonic acid gas through a solution of basic acetate, as he directs.

The objection to the Bradley process lies in the fact that, to produce a given amount of white lead, it is necessary to keep double the equivalent amount of lead oxide in solution all the time.

The white lead produced by the Bradley method has a very good body, and its chemical composition is such as to justify him in claiming that it would make a very good paint.

It has also been proposed to mix a small portion of acetic acid with litharge and expose the mixture to an atmosphere of oxygen, steam and carbonic acid gas. The product thus obtained makes a very superior quality of white lead, but the objection to this method is the same that applies to the method of corroding the finely divided lead in revolving cylinders; that is, some of the litharge may not be acted upon, and would contaminate the product.

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* I regret to say I cannot give my authority.

The process which I am about to describe is based upon the fact that, if finely divided litharge be stirred into a solution of normal acetate of lead, in the proper proportions and at the proper temperature, the mixture *crystallizes*.

If we expose these crystals to the action of carbonic acid gas, we obtain a basic carbonate of lead, together with normal acetate of lead in solution. The basic carbonate so obtained is similar in composition to that produced by the Dutch process, and is amorphous.

The method of operation may be briefly described as follows: We will take, for example, a solution which marks about 15½° B., and contains about 14 per cent. of normal acetate of lead, which is equivalent to say 7 pounds of oxide of lead to the cubic foot of solution. In order to form the crystalline compound above named, therefore, it is necessary to mix with it an amount of litharge corresponding to 14 pounds of litharge to the cubic foot of solution employed.

We have found that it is possible to saturate partially the solution of normal acetate, by digesting unground litharge in it, and then to supply the final amount necessary to make the tri-basic acetate in the form of very finely ground litharge. As it is necessary to use litharge which has been passed through a bolting-cloth of about 200 meshes to the linear inch, it is advisable to saturate the solution with the coarse litharge to an extent such as will require the addition of a comparatively small proportion of fine litharge to complete the operation.

The partially saturated acetate solution is run into a copper vessel, with a double bottom or steam jacket, and provided with a stirring apparatus consisting of revolving arms. It is heated to about 140° F.; the revolving arms are set in motion, and the ground litharge is added. In from five to ten minutes the mixture crystallizes into a curdy mass. This mass is then exposed in the same vessel to the action of carbonic acid gas. The crystals melt in proportion to the conversion into white lead. The white lead formed is transferred to a filter-press, in which it is separated from the solution of normal acetate, and the latter

is used again for a fresh supply of litharge, thus making the process a continuous one.

The process is readily controlled. With a given solution of normal acetate, it is simply necessary to weigh out and incorporate therein the requisite amount of litharge, in case the whole amount is added in the form of a fine powder. Where the solution is partially saturated by the use of coarse litharge, the process must be controlled by sampling the partially saturated solution, and determining the amount of lead oxide therein contained.

The white lead produced by this process has the same composition as that produced by the Dutch method. It may be interesting to compare the analysis of the white lead produced by the Clichy method, the Bradley method, the method I am describing, and the Dutch method.

The lead produced by the Dutch process has the general formula $2PbO, CO_2, PbH_2O_2$; that is to say, it contains two equivalents of carbonate of lead and one equivalent of hydrated lead oxide. The lead produced by our method has the same approximate formula. The lead produced by the Bradley method also is very near the typical formula of good white lead. The lead produced by the Clichy method is almost a pure carbonate of lead. It contains a very small amount of hydrated oxide.

The following analyses give the approximate composition of the product of these different methods:

	Per Cent.		
	PbO	*CO_2*	*H_2O*
Thènard lead, made by the Clichy process, .	83·42	15·76	0·59
Lead made by the Bradley process	86·16	11·93	1·81
Lead made by the Tatham process	86·33	11·34	2·15

The following are analyses of white lead produced by the Dutch method, in England and Germany, respectively, taken from Wagner's Chemical Technology:

	Per Cent.		
	PbO	*CO_2*	*H_2O*
English white lead	86·51	11·30	2·23
German white lead	86·40	11·53	2·13
White lead having the formula $2PbCO_3$, H_2PbO_2, would have the composition . . .	86·32	11·35	2·32

CORRESPONDENCE.

WORTHINGTON COOLING TOWER.

PHILADELPHIA, September 2, 1896.

The Editor Journal of the Franklin Institute.

DEAR SIR:—On reading in the June number of the *Journal* an article on the Worthington Cooling Tower, I was reminded of a device used by me for the same purpose while erecting the machinery in a flour-mill at Hamburg in 1862.

The engine was a Woolf beam engine (cylinders 24 and 45 inches diameter), and the discharge from the air-pump was carried to the roof of the boiler-house (a low structure, adjoining the mill), over which the condensing water ran, passing over a number of ridges formed on the roof (which was of tin), and then falling into a well, from which it was again taken for injection into the condenser. In this manner the condensing water was sufficiently cooled to give a vacuum of 24 to 25 inches in winter and 22 to 23 inches in summer.

Hoping this may be of interest, I remain,

Yours truly, JOHN HAUG.

206 WALNUT PLACE.

NOTES AND COMMENTS.*

PENNSYLVANIA'S TIN-PLATE INDUSTRY.

Pennsylvania turned out a total product of 104,375,366 pounds of finished tin- and terne-plate for the year ending December 31, 1895, with an aggregate value of $4,237,819.42, or an average value of $81.20 per net ton. Add to the $1,161,424.58 paid out in wages by the 10 tin-plate works manufacturing black-plate, the $188,224.32 paid out in wages by the 17 dipping works, and the result is $1,349,648.90 paid out in Pennsylvania for labor in the manufacture of tin-plate during 1895. That is to say, the 2,574 persons employed by the black-plate makers, and the 557 persons employed by the dippers, in all 3,131 persons, working an average time of 241.6 days each, received *per capita* for skilled and unskilled labor, $431.06, or an average of $1.79 per day.

* From the Secretary's monthly reports.

Seventeen of Pennsylvania's tin-dipping works were in operation an average of 244 days, in 1895, and employed 557 persons. The aggregate amount of wages paid to these 557 employés was $188,224.32, an average *per capita* of $337.92, or $1.38 for all persons employed. These 17 plants turned out a finished product of 54,873,636 pounds, with value of $2,453,464.68, an average of $89.62 per net ton. In round numbers, Pennsylvania has one-third of the black-plate (tin-plate) manufactories in the country, and over 50 per cent. of their entire capacity. The Pennsylvania works undoubtedly represent some of the largest, best equipped and most successfully operated tin-plate plants of any country.

ELECTROLYSIS OF CHLORIDES.

The *Electrical World* summarizes the conclusions of Andreoli on the relative value of the several commercial processes for the electrolysis of common salt, in these terms. He considers the Castner process far superior to that of Richardson and of Holland. Mercury is used, not as a cathode, as is generally believed, but as a diaphragm; stress is laid on the absence of hypochlorite, which is a serious drawback in the other process; his anodes are made of retort carbon submitted to a very high temperature in contact with different substances. The method of Hargreaves, based on the use of porous partitions on each side of the positive compartment, and of the two dry negative compartments, is said to give a yield of 92 per cent. The results obtained with the Le Sueur process, it is claimed, do not bear comparison with the others. According to Hargreaves, it is better from a commercial point of view to make carbonate of soda than caustic soda. Each of the three processes are absolutely different from the other, and Andreoli considers it an accomplished fact that they have solved the problem commercially. Electrolysis can compete with the chemical methods as far as purity and cheapness are concerned, and the electrical method is far superior as regards simplicity of installation, besides being more sanitary. The Hargreaves process, in the author's judgment, promises to be the cheapest.

PIG IRON PRODUCTION IN THE FIRST HALF OF 1896.

Mr. Swank publishes, in a recent issue of the Bulletin of the American Iron and Steel Association, the following statistics of the production of all kinds of pig iron in the United States in the first half of 1896, viz.:

The total production of pig iron in the United States in the first half of 1896 was 4,976,236 gross tons, against 4,087,558 tons in the first half of 1895, and 5,358,750 tons in the second half of 1895. As compared with the first half of 1895, there was an increase in the first half of 1896 of 888,678 tons, and as compared with the second half of 1895, there was a decrease of 382,514 tons.

The production of pig iron of Bessemer quality in the first half of 1896 was 2,793,672 gross tons, against 2,402,023 tons in the first half of 1895, and 3,221,672 tons in the second half.

RAILROAD BUILDING IN 1896.

The records of the new railroad building in the United States in 1896, which have been gathered by the *Railroad Gazette*, show that 717 miles of road have been built in the first half of the year. The total is not very different from the amount of new railroad which has been constructed in the first half of any year, since the conditions in 1893 called a sharp halt in railroad building. Last year 622 miles of new road were built up to July 1st, and the record in 1894, only 495 miles between January 1st and July 1st, showed how decisively extension work had been stopped. Figures as to the new track built in the first half of the year for seven years past make some interesting comparisons:

1896.	1895.	1894.	1893.	1892.	1891.	1890.
717	620	495	1,085	1,284	1,704	2,055

It will be seen how greatly railroad extension has been checked by the conditions of the past few years, and there are no substantial signs to encourage the belief that any large relative increase is to be expected in the near future.

TECHNICAL NOTES.

Tin Scrap.—The *Engineering and Mining Journal* quotes the statement of Mr. Swinburne, of London, in a recent lecture, that it was easy enough to recover tin from scrap electrolytically in a solution of hot caustic, but the difficulty was to find the scrap from which to skin the tin, as no one seemed to have any for sale. We may note that a considerable quantity of tin scrap is shipped from this country to Europe, chiefly from Baltimore. It is gathered up from the factories which supply the extensive canning establishments of Baltimore and the Eastern Shore.

A Magnesium Light for photographic purposes is described in the *British Journal of Photography*, as a safe and efficient substitute for magnesium wire or ribbon, which is known to be more or less unreliable.

The new method of burning the metal is said to offer a perfectly satisfactory "actinic combustion." The method of preparing the medium is described as follows:

It consists in the "sandwiching" of magnesium powder between sheets of paper impregnated with potassium chlorate. Magnesium powder is placed between two sheets of paper, which have been pasted over with starch. The whole, when dry, forms one single sheet. Next, each side is covered with a piece of paper impregnated with potassium chlorate, and the whole covered with a further sheet of paper pasted on each side, a thick sheet, almost like card-board, being thus produced. It may then, when perfectly dry, be cut into lengths and ignited as required. According to the *Journal of Chemical Industry*, the combination is quite safe and keeps well.

BOOK NOTICES.

Chemical Experiments, General and Analytical, for use with any text-book of chemistry, or without a text-book. By R. P. Williams, Instructor in Chemistry in the English High School, Boston, etc. Boston: Ginn & Co. 1895. Price, 60 cents.

The author gives in this work a series of illustrated practical lessons in chemical manipulations and in analytical work, arranged in a rational order to meet the requirements of the chemical student. The book should prove of value in supplementing the analytical guides employed in the laboratory, and instructors in chemistry will doubtless be quick to apprehend its utility.

W.

A Prime of the History of Mathematics. By W. W. Rouse Ball, Fellow and Tutor of Trinity College, Cambridge. London and New York: Macmillan & Co. 1895. Price, 65 cents.

The author's purpose in this primer is to give a popular account of the history of mathematics, with some notice of the lives and environment of those to whom its development is due; and it is intended chiefly for the use of teachers and learners, to whom the larger works on the subject are not accessible, or who may not have the time to read them. The sketch will be found both interesting and useful to those engaged in the study of this branch of science.

W.

The Chicago Main Drainage Channel. A description of the machinery used and methods of work adopted in excavating the 28-mile drainage canal from Chicago to Lockport, Ill. By Charles Shattuck Hill, C.E., associate editor *Engineering News*, etc. With 100 illustrations and an index. New York: Engineering News Publishing Company, 1896. Price, $6.50.

The engineering fraternity at home and abroad will, doubtless, prove duly appreciative of the opportunity afforded by this publication of obtaining in collected form the valuable series of articles on the great drainage canal of Chicago, which appeared in *Engineering News* during the past year.

The author very justly refers to this undertaking, now rapidly approaching completion, as one of the greatest works of constructive engineering in the world—a statement that will doubtless be received with surprise by many who have given the subject only incidental attention.

The present book contains an historical sketch of the causes which originated the enterprise, and describes in elaborate detail and with a profusion of illustration its engineering features and the methods and machinery employed in its excavation. It will be found especially valuable for reference, from the incorporation therein of full tables giving the cost of every portion of the work.

It is interesting to note the fact that this excavation was of a very variable nature, on which account, and because of the policy pursued of letting out

the work in short sections to many individual contractors, the progress of the work served the useful purpose of developing a great variety of methods of doing the work, thus affording the professional observer an excellent opportunity of comparing the results and forming an intelligent judgment of the comparative efficiency of many different machines. This element is rendered more valuable from the fact that many of the methods and devices developed were extremely novel.

The author has made numerous additions to the articles as they originally appeared in *Engineering News*, and has revised the data to date of publication. W.

The Mineral Industry: its Statistics, Technology and Trade. United States and other countries. 1895. Edited by Richard P. Rothwell, Editor of the *Engineering and Mining Journal*, ex-president American Institute of Mining Engineers, etc. Vol. IV. New York: The Scientific Publishing Company. 1896. Price, $5.

The annual volume of "The Mineral Industry," edited by Mr. R. P. Rothwell, the editor of the *Engineering and Mining Journal*, fortunately for all interested in the progress of mineral and metallurgical industries, appears to have become an established institution.

There is no publication, so far as we know, that compares with it in the extent and completeness of its statistical data, and in the variety of subjects embraced therein in the form of special contributions.

The present volume constitutes the fourth of the series which we have had the pleasure of reviewing, and, like the others, contains a vast amount of valuable material, well classified and arranged for reference.

The editor has been as fortunate as in the earlier volumes, in securing the services of many eminent specialists, in the preparation of special chapters, and the volume before us will add substantially to the value of the series, which has become an indispensable work of reference. W.

Matte Smelting: its principles and later developments, with an account of the pyritic processes. By Herbert Lang, mining engineer and metallurgist. New York: The Scientific Publishing Company, 1896. Cloth, price, $2.

Mr. Lang's contribution to the subject of matte smelting will be appreciated by metallurgists as an intelligent effort by a competent expert to give an independent systematic treatment of this generic class of processes. Heretofore, they have been discussed in connection with copper smelting, silver smelting, etc. Mr. Lang's treatment affords a better and more scientific view of the method.

The various methods, such as the reverberatory, pyritic and German systems, are treated in detail.

The series of tables given at the close of the volume embraces a great amount of valuable information respecting ores treated, fluxes and fuels, products obtained, results of assays and other important data.

The work is an original and valuable contribution to the technology of this important class of metallurgical methods. W.

Franklin Institute.

[*Proceedings of the stated meeting, held Wednesday, September 16, 1896.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, September 16, 1896.

JOS. M. WILSON, President, in the chair.

Present, 105 members and visitors.

Additions to membership since last report, 6.

Mr. S. Albert Reed, of New York, by invitation, presented a communication, giving a *résumé* of the plan and scope of the important experimental work now being carried on by "The Committee on Fire-proofing Tests." This committee is appointed by the Architectural League of New York, the Tariff Association of New York and the American Society of Mechanical Engineers, to investigate and test methods of fire-proofing structural metal in buildings and to obtain data for standard specifications.

The speaker illustrated his subject with the aid of a series of lantern slides, showing the furnace and other apparatus used in making the tests, and the appearance of the specimens (steel and cast-iron columns of standard sections and actual size employed in buildings) before and after being subjected to the action of fire, and of fire and water, while being maintained under a uniform load (82 tons). The communication evoked considerable discussion, at the close of which the speaker received a vote of thanks. The paper of Mr. Reed will appear in the *Journal*.

Mr. C. J. Reed, of Philadelphia, exhibited in operation the so-called carbon battery, devised by Dr. Jacques, of Boston, Mass., and gave a critical discussion of the principle of its action. Mr. Reed's experiments appeared to demonstrate, beyond reasonable doubt, that the cause of the development of energy in this apparatus is thermal, and not, as has been claimed, electrolytic.

The speaker also exhibited and described what he termed a thermotropic battery, which depended for its action upon certain new and interesting thermo-electric phenomena which he had observed. (Mr. Reed's paper will be published.)

The Secretary exhibited and made some reference to certain specimens of a product called "ductile cast iron," manufactured by the East Chicago Foundry Company, and presented therewith the records of several series o physical tests of the same, which were submitted by the manufacturers in substantiation of the claims made for the product.

The meeting passed a vote of thanks to the members of the Board of Managers and others who had contributed to the expense of repainting, papering and decorating the lecture room, and the meeting was adjourned.

WM. H. WAHL, *Secretary*.

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA,

FOR THE PROMOTION OF THE MECHANIC ARTS.

VOL. CXLII. NOVEMBER, 1896. No. 5

THE Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal.*

THE FRANKLIN INSTITUTE.

Stated Meeting, held Wednesday, September 16, 1896.

MR. JOS. M. WILSON, President, in the chair.

WORK OF THE COMMITTEE ON FIRE-PROOFING TESTS.

BY S. ALBERT REED, PH.D.

The Term "Fire-Proof."—Fire underwriters use the term fire-proof generically, denoting a class of construction in which no structural member is combustible, with full appreciation of the fact, however, that fire may cause complete wreck without actual combustion of the structure. Some of those practically interested have undertaken to investigate the causes and nature of damage from fire to this class of structure. A co-operative committee of three was formed nearly a year ago, representing officially the principal associations of Fire Insurance Underwriters, the Architectural League and the American Society of Mechanical